

# **FINAL REPORT**

## **VOLUME 2**

### **DEFINITION OF AVIONICS CONCEPTS FOR A HEAVY LIFT CARGO VEHICLE**

**for Marshall Space Flight Center**

**Contract Number NAS8-37578**

**September 1989**

**GENERAL DYNAMICS**

***Space Systems Division***

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16. Abstract The major objective of this study task was to define a cost effective, multi-user simulation, test, and demonstration facility to support the developments of avionics systems for future space vehicles. The technology needs and requirements of future Heavy Lift Cargo Vehicles were analyzed and serve as the basis for sizing of the avionics facility although the lab is not limited in use to support of Heavy Lift Cargo Vehicles. This volume of the final report is the technical volume and provides the results of the vehicle avionics trade studies, the avionics lab objectives, the lab's functional requirements and design, physical facility considerations, and a summary cost estimate.			
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## 1.0 INTRODUCTION

The Final Report (Volume 2), of the National Aeronautics & Space Administration study, "Definition of Avionics Concepts for a Heavy Lift Vehicle" was written by the Space Systems Avionics Group of General Dynamics. It was performed under contract NAS8-3578 for the Marshall Space Flight Center.

### 1.1 Scope

This document contains:

- A summary of significant achievements and activities of the study effort.
- Technical analysis and trade studies with necessary data to support the conclusions.
- System and subsystem conceptual designs for reference vehicles and the Ground Based Testbed (GBT) with rationale for selection or rejection of the considered alternatives.

The Final Report (Volume 2) also contains the majority of the material presented in the four quarterly reviews. Any study material not contained in this volume is in volume 3 (Program Cost Estimates) or was felt to be redundant or superceded by the material presented.

### 1.2 Background

The HLCV avionics study was originally meant to focus the development of advanced avionics systems for various space vehicles for the next ten to fifteen years. Figure 1.2-1 shows the role the HLCV Avionics study was envisioned to play. Scoped to start with an expendable, Shuttle derived booster, it was to define an optimum progression of upgrades and transitions until a fully reusable fixed wing booster system was achieved. Not limited to boosters, the study was to explore second stages, recoverable modules, and the attendant ground support systems.

Methods for accelerating the application of beneficial new technologies to existing and future systems were needed. To this end, a Ground Based Testbed was to be defined. Though not a stated goal, lowering the overall cost per pound of orbiting a payload drove the study to include the definition of the optimal mix of ground and airborne check out capability. Autonomous operation of the far term vehicles was felt to be a logical goal.

Shortly after the first review, the customer directed a shift in emphasis to a more detailed definition of the Ground Based Testbed, (GBT), that would support development of the HLCV avionic systems. The HLCV reference vehicle avionic systems were defined to the level required to size the GBT main processor, G&N Extension, and interconnecting busses and networks.

A target implementation schedule was provided by MSFC in October linking the HLCV GBT and the Marshall Avionics System Test bed (MAST) efforts (see Figure 1.2-2.). Also defined were specific functional support levels with dates and projected budget allocations. A candidate site for the GBT/MAST was also provided. The third Quarter Review reflected these

inputs and specifically costed the Phase 1 lab configuration. For purposes of this study the terms MAST and GBT are synonymous.

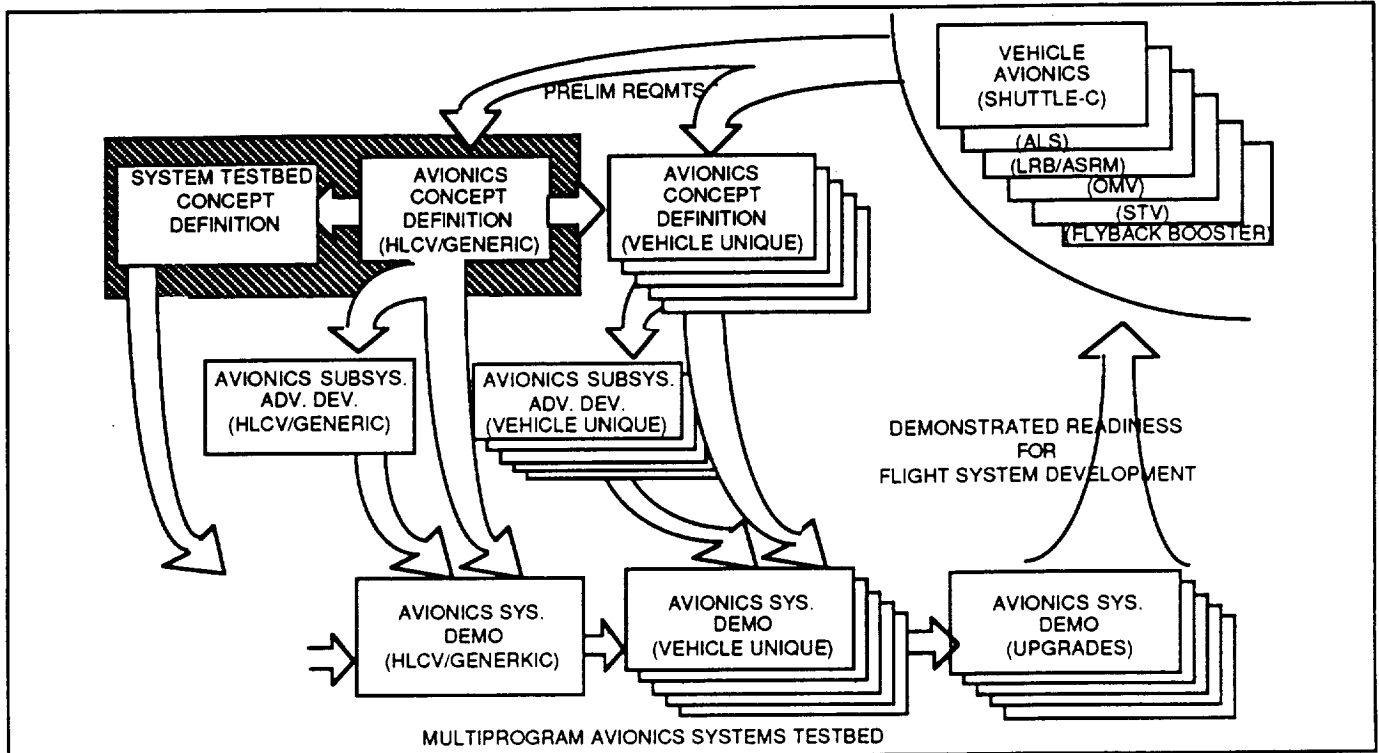


FIGURE 1.2-1. HLCV AVIONICS STUDY: FOCUS FOR AVIONICS ADVANCED DEVELOPMENT

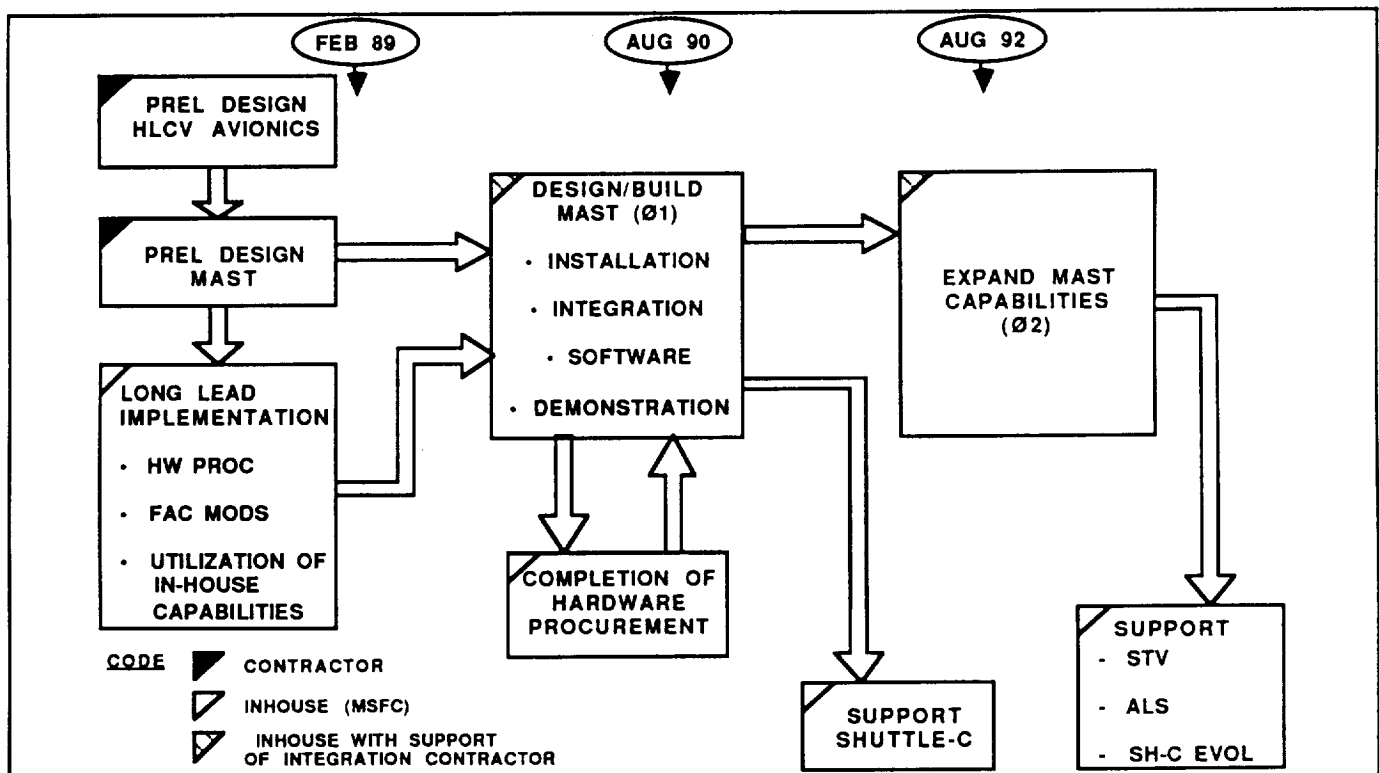


FIGURE 1.2-2 HLCV / MAST IMPLEMENTATION



### 1.2.1 Study Objectives

The initial objectives of the study were enumerated in the Study Plan as:

1. Define the avionics requirements and recommended avionics concepts for an expendable Heavy Lift Cargo Vehicle in the 1992-1995 time span.
2. Define the avionics requirements and recommended avionics concepts for a highly reusable HLCV to be operational in the 2000 era.
3. Define the requirements, concepts, developmental plans, and costs for an avionics test bed(s). The avionics test bed will support the development and testing of the recommended vehicle and vehicle support components, software modules, subsystems and systems.
4. Develop a transition plan from the expendable to the highly reusable HLCV.
5. Develop a follow-on plan to define advanced development activities.

As previously stated, the study emphasis shifted to definition of the avionics test bed, Objective #3, shortly after the first Quarterly review. Details were hammered out in the August Technical Interchange Meeting (TIM). The study plan was changed and a no-cost contractual change initiated to offset the additional tasks and products associated with this change, objectives 4 and 5 were re-scoped and de-emphasized.

### 1.2.2 Study Tasks & Schedules

Figure 1.2.2-1 is the revised Master Schedule that reflects the final contract changes. The six major task classifications are shown and the deliverables identified.

#### 1.2.2.1 Technology Assessment

This task consisted primarily of completing the data base of relevant technologies that would be involved in the avionics system design of the three reference HLCV configurations. Section 2 lists nine of these technologies. They range from Computer Languages to large Electro Mechanical Actuators. The most promising candidates were chosen for Trade Studies.

#### 1.2.2.2 Trade Studies and Technical Analysis

This activity continued far beyond the original estimates. With a change in emphasis to the definition of the GBT, trade studies or some level of technical analysis were performed beyond the 3rd Quarterly Review. Initially, trades were performed on the feasibility of using non-STS avionics equipment in the initial HLCV. Section 3 of the Final Report contains the RVU/EIU study which is typical of this type of trade. It was the "Tech Demo" to determine the best Main Processor for the GBT that extended beyond the planned time. This study considered over 20 candidates who were evaluated against criteria based in GBT processing and use requirements. The final selection will be based upon actual performance on contractor and customer supplied benchmark programs.

### 1.2.2.3 Requirements

Initially centered on the three HLCV avionic system configurations, these requirements shifted to defining the GBT functional capabilities and interfaces. Section 4 covers these vehicle and GBT requirements.

### MASTER SCHEDULE

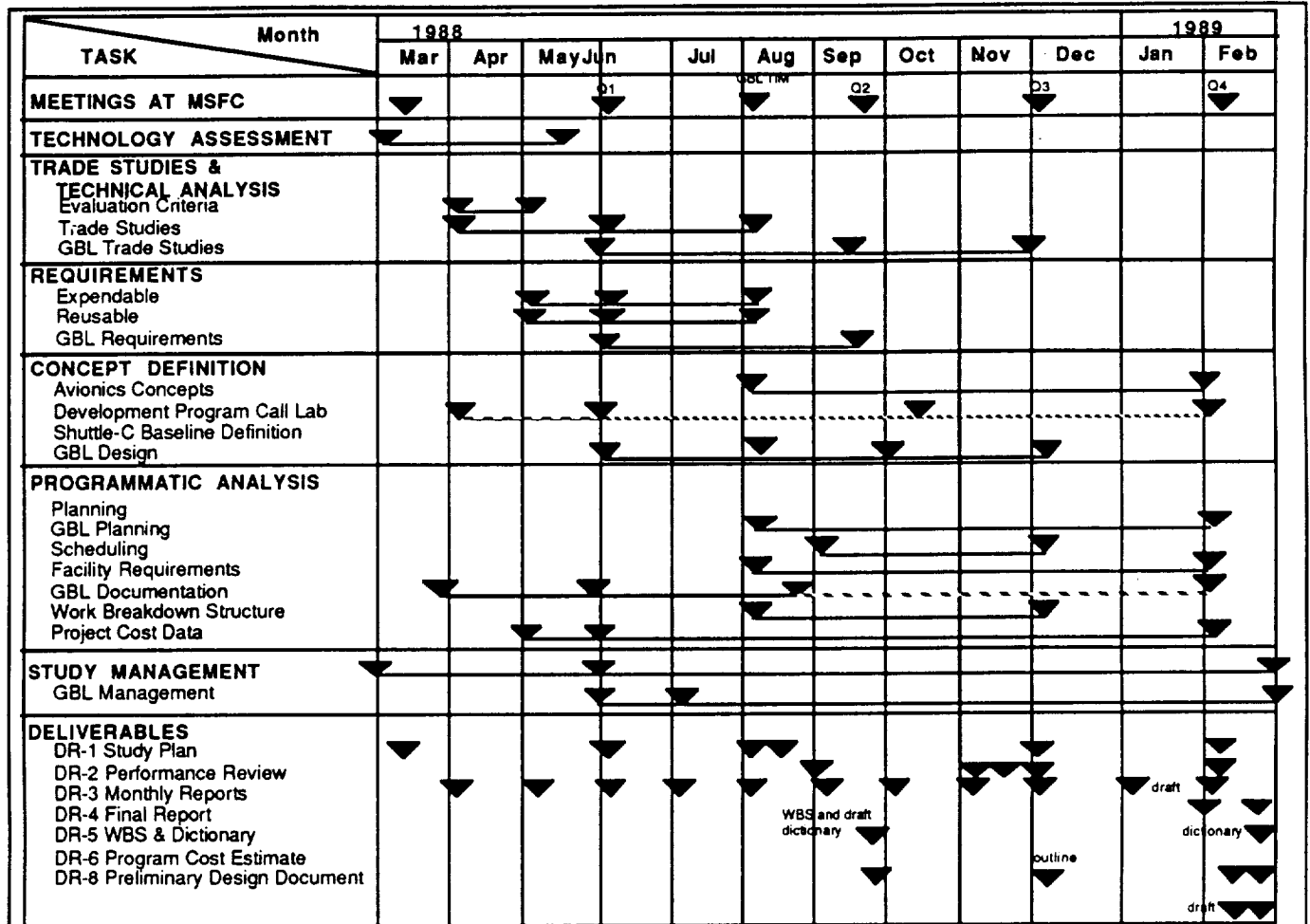


FIGURE 1.2.2-1 REVISED MASTER SCHEDULE

### 1.2.2.4 Ground Based Testbed Design Definitions

Formally called Concept Definition, these task represents the culmination of the three preceding tasks. The GBT design includes a three step implementation schedule which has specific support capabilities linked with developing programs. The design includes both hardware and software. The scope of definition includes Phase 1, Phase 2 and the "full up", or Target configuration. Design details of the Phase 1 configuration are sufficient to cost the hardware and software. Phase 1 interface details is also provided in the Preliminary Design Document. Section 4 details all three GBT configurations.

### 1.2.2.5 Programmatic Analysis

Three subtasks dominate this activity. The first in importance is GBT implementation planning. Several variables factored into this analysis are:

- Customer Provided Goals & Missions
- Development Schedules of Programs to be Supported
- Availability of Hardware and Software
- Facility Availability/Modification Schedule
- Funding levels

The Facility Requirements are driven by the Target GBT configurations and the implementation schedule. Funding for facility modifications may come from different sources than that of the GBT itself. This would represent still another driver of Facility Requirements.

The GBT documentation, which includes the Cost Data, is a very important product. Though addressing the final or Target Configuration at a survey level, the GBT documentation covers the initial Phase 1 configuration thoroughly enough to cost the hardware and software.

#### **1.2.2.6 Deliverables**

The contractual Data Requirements (DR's) are shown on the bottom of Figure 1.2.2-1.

## **2.0 GROUND BASED TESTBED (GBT) DESIGN OBJECTIVES AND PHILOSOPHY**

The GBT is envisioned as a general resource facility providing to new vehicle programs a cost effective method of evaluating the concepts and technologies employed in their design. This resource will permit complete end-to-end simulations of system operation in the simulated mission environment desired.

The GBT is to be set up to encourage use by all HLCV era vehicles during their initial design phases. Review of past projects involving total vehicle or subsystem development have repeatedly shown the need for such a readily accessible and powerful test and evaluation facility. The traditional dedicated test and development facilities have not been able to support their projects early enough to optimize system requirements and design. New projects must initially use facilities dedicated to other projects. Seldom do such facilities provide all the necessary testing capabilities or time for the required work.

The key to the HLCV GBT success is seen to simply be: Cost Effectiveness. To obtain this objective, the Lab must be readily accessible at the time when new projects traditionally don't have their own dedicated facilities. GBT access must be simple and bound with a minimum of red tape. Once accessed, the GBT must provide a user friendly environment, an environment that can quickly be configured to access the required testing and logging resources. The resources must be capable of evaluating the concepts, technologies or designs to the required level of accuracy and against recognized performance benchmarks. Finally, the GBT must provide not only easy replication of the testing, but also provide the ability to thoroughly analyze the results and report the results in forms which effectively communicate their significance.

## 2.1 GBT Objectives

The major objectives for the GBT are to provide a cost effective, multi-user simulation, test and demonstration facility to:

- 1 Support early development and quantitative evaluation of proposed avionics systems during the early phases, (phase A/B), of a program.
  - Surfaces avionics, systems, integration and software problems early
  - Supports early requirements development
- 2 Accelerate new avionics technology testing and application to future programs.
- 3 Provide a productivity center for evaluating/demonstrating major new design advances from NASA and industry.
- 4 Promote continuity of avionics architectures, software, and hardware across projects.
- 5 Demonstrate the "integration-ability" of new subsystems or components and their impact on the performance of an existing vehicle system.

Figure 2.1-1 shows four HLCV era vehicles to be supported by the GBT. The first two are shuttle derived vehicles, SDV-2ES and SDV-2R. The 2R version has reusable propulsion and avionics as opposed to being expendable as the 2ES is. An alternative to the SDV-2RS is the Advanced Launch System Core and Booster. The fourth GBT supportable vehicle shown is the Fully Reusable Booster/Partially Reusable Cargo Vehicle, FRWB/PRCV. In addition to these, the GBT will also support upper stages, the Space Transfer vehicles, and several payloads.

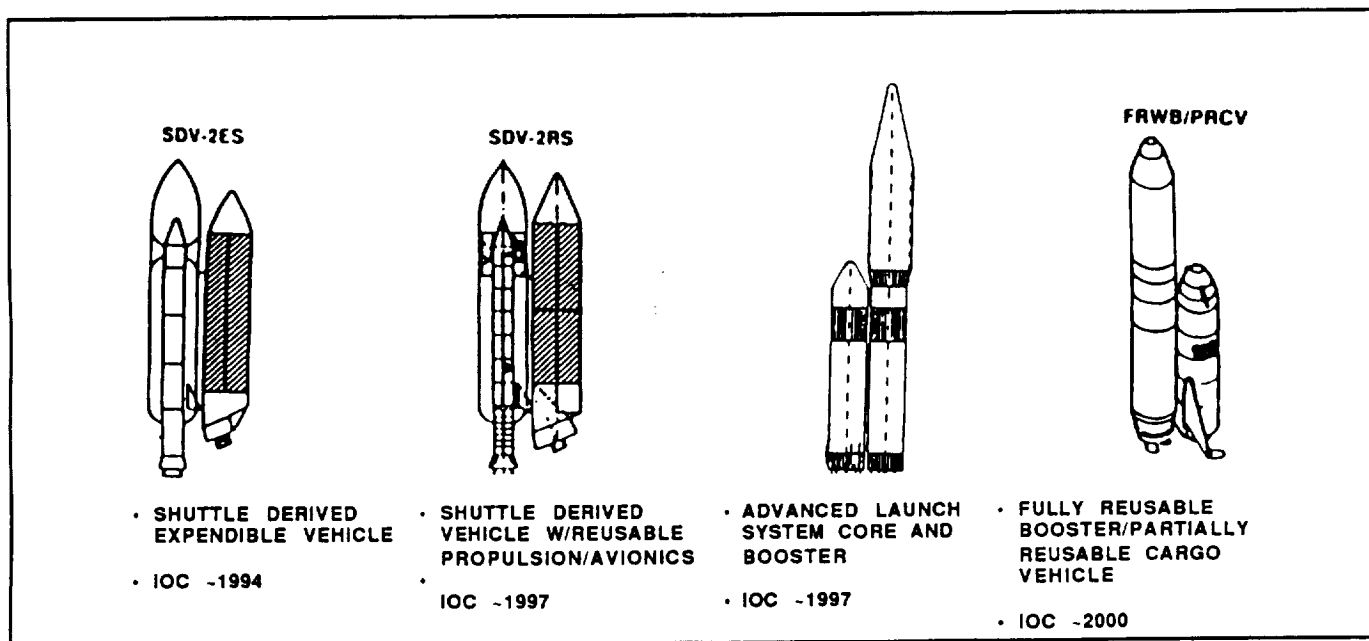


FIGURE 2.1-1 HLCV ERA CANDIDATE VEHICLE CONFIGURATIONS

## 2.2 GBT Philosophy

The major points upon which the GBT design philosophy is based are:

- a. Reconfigurable Design

- b. Real Time
- c. Functional Testing
- d. Modular Design
- e. Flexible
- f. Demonstration Oriented
- g. User Friendly

The broad based, non project dedicated, generic nature of the GBT is implied in the first point. The GBT must be an evolving facility, capable of supporting several current and near term avionic systems. This translates to a firm requirement for rapid reconfigurability. It must not only be able to switch from one test configuration to another, but it also must have sufficient capability to support several parallel efforts simultaneously. These efforts will include everything from basic evaluation of single units in an open loop environment, to full up, multi-string system simulation.

To be truly useful to a number of projects simultaneously, the GBT must accommodate a variety of software and hardware configurations. This characteristic encompasses several traits which include an continuing capability to support several current and near term avionic systems. Implicit to this capability would be a rapid and easy reconfigurability made possible by an architecture that presents a broad compatibility to both hardware and software. This compatibility includes the ability to provide a Real-Time hardware and software interface. This interface must be capable of duplicating the normal interface the Unit Under Test encounters in its native system. Only with such an interface can testing and evaluation be carried out at the required level of fidelity. Just as important is the ability to precisely manipulate the interface characteristics. Fault insertion and off limit operation can enhance the thoroughness of testing.

The GBT is modular at all functional levels so, as it develops and the support requirements change, the lab can add or access the required resources. This translates to the GBT being able to accommodate any vehicle or system simulation of similar complexity to the then current defined reference vehicle and systems. Modular design in both the GBTs hardware and software facilitate an orderly expansion of capability. The foundation of hardware model benchmarks will be validated against real equipment. Once proven, a combination of real and simulated hardware models can be utilized to evaluate any number of proposed system architectures.

Since one of the GBTs primary functions is to provide timely support to new projects, it must have the ability to quickly adapt to the specific needs of those projects. This flexibility must be a basic consideration in the GBT architecture so it can perform that level of testing or simulation required in a more cost effective manner than currently available to new projects.

The current implementation plan for GBT establishes an August 1990 IOC to support Shuttle-C, (figure 1.2-2). In actuality, the GBT will have more than half of its total planned capability at this point. The software tools and models developed for the Shuttle-C are basically generic in nature, with separate data files supplying the unique values for this vehicle, its subsystems, and mission profiles. In most cases, only data set value changes would be required to switch from one vehicle configuration to another.

### 3.0 TRADE STUDIES AND TECHNICAL ANALYSIS

Several technical issues had to be resolved prior to the definition of the three HLCV avionic system designs and the Ground Based Test Bed.

The range of studies and analysis originally considered covered the three HLCV reference vehicles and the GBT. Those chosen for further study included:

- Vehicle Processors
- Software Language and Tool Selection
- Inertial Measurement Unit
- RVU replacement of EIU
- Flight Control Actuators
- Vehicle Power
- Ground Systems
- Lab Architecture
- Data Buses and High Speed Networks
- Instrumentation - Data Acquisition Systems
- GBT Main Processor Selection

#### 3.1 Vehicle Processors

The Vehicle Processor trade studies looked at currently available and developing 16 and 32 bit CPUs for application in the full range of HLCV reference vehicles. Selection of the best current CPU for the HLCV centered about the 16 bit, 1750 processors. Figure 3.1-1 shows the units investigated. Figure 3.1.1-1 shows the 32 bit processors considered for far term application.

##### 3.1.1 Vehicle Processor Selections

Due to the rapidly changing developments in this area, the majority of this study effort was spent on candidate processors for near term application. Criteria used in evaluation included: Availability, Risk, Performance and broadness of application, (Use). The PSC 1750A was selected for near term applications due to its current levels of performance, qualification and support. The 32 bit processor analysis shown reflects graphically the rapidly changing picture in that area. Completed in May of 1988, the most promising candidate the MC6830 would be hard pressed today, by the MC88000 and other newly introduced CPUs.

##### Results:

- Additional research required to select the optimum 32-bit processor
  - Space qualification, SEU hardness
  - Hardware cost and software support
  - Industry support
- Note: 1740 will have lots of legacy and support well into the year 2000
  - B-2, V-22, F-16C/D (Block 40G)
  - Centaur, Titan (proposed)
- ATR/ATA
  - GD baselined today is 32 bit avionics
  - Flight control undecided (Currently 1750)

	Availability	Risk	Cost	Performance	USE			Rating
					Air	Ground	Lab	
Existing PSC	88	Lowest	Lowest	1.3-2.6	✓			<div>Best</div> <div>↑</div> <div>↓</div> <div>Lowest</div>
PACE 1750A	now	Moderate	TBD	1.3-2.6	✓			
Improved PSC								
RCA CMOS/SOS	TBD	High	High	High	✓			
PSC 1750A								
RCA CMOS/SOS 1750A	88		TBD	2.8	✓			
HI RICMOS GVSC	89		TBD	1.1-3.7	✓			
Self-Checking PSC	now	Moderate	Low	1 - 2	✓			
PACE 1750A								
LSI Logic L64500	now		TBD	900k	✓			
UTMC 1750A	now		TBD	750k	✓			
MACDAC 281	TBD		TBD	600k	✓			
Fairchild F9450	Now		TBD	700K	✓			
Mikros M2750	Future		TBD	High	✓			
TISLC 1750A	TBD	High	TBD	High				
PACE II 1750A	Near Term			3.5 MIPS at 40M Hz				
CDC 444 1750								
CMOS DOS	Near Term			3 - 4 MIPS				

FIGURE 3.1-1. TECHNOLOGY MATRIX - 1750 PROCESSORS

	Availability	Risk	Performance	USE		
				Air	Ground	Lab
MC68030	NOW	LOW	TBD	✓		
MC68020	NOW	LOW	3.5 MIPS	✓		
80386	NOW	LOW	4 MIPS	✓		
Z80000	NOW	LOW	5 MIPS	✓		
T414	NOW	LOW	6-20 MIPS	✓		
NS37332	NOW	LOW	3 MIPS	✓		
NS32032	NOW	LOW	1.5 MIPS	✓		
WE32100	NOW	LOW	3 MIPS	✓		
NCR/32-000	NOW	LOW	3 MIPS	✓		

FIGURE 3.1.1-1. TECHNOLOGY MATRIX: 32 BIT PROCESSOR

## Recommendations:

- Select existing PSC 1750A design
  - High SEU Tolerance/Latch-up immune
  - 1.4 MIPS throughput at 25 MHz (2.5 MIPS at 40 MHz)
  - Bulk/SOS Conversion already performed on gate array

### 3.2 Computer Languages

Nine criteria were examined in selection of the software language to be used in the GBT, Vehicle, and ground Checkout facilities. Figure 3.2-1 summarizes these results. Ada was chosen for use in vehicle software related functions with "C" selected for use in special test equipment and small simulations until software and tools become available in Ada.

	Compatability	Availability	Risk	Cost	PERFORMANCE		USE		Rating	
					Speed	Lines of Code		Ground	Lab	
Ada	Excellent	Now	Low	Low	Very Good	Low		✓	✓	Excellent
Jovial	Good	Now	Low	Moderate	Good	Low				Good
HAL/S	Poor	Now	Low	Moderate	Very Good	Low				Acceptable
Assembly	Good	Now	Low	Very High	Excellent	Highest		✓	✓	Acceptable
"C"		Now	Low	Low	Good	Low			✓	Excellent
Fortran	Very Good	Now		High	Good	Moderate		✓	✓	Good
Goal	Poor	Now	Low	High	Moderate	Moderate		✓	✓	Acceptable
Dist. Ada	TBD	Near	Low	Lowest	Excellent	Low		✓	✓	Very Good

FIGURE 3.2-1. TECHNOLOGY MATRIX - COMPUTER LANGUAGES

### 3.3 Inertial Measurement Unit

Candidates for near and far term HLCV inertial sensors were evaluated in this study. Though guidance and navigation technologies are not fully dependent on this type of sensor, it is felt that with the future shift to autonomous operations, inertial sensors will continue to play a significant role. Figure 3.3.2-1 reviews the spectrum of Guidance and Navigation Technologies. Figure 3.3.2-2 shows the inertial measurement units compared. Criteria used in this evaluation included: availability, accuracy, compatibility cost, and technical risk.

#### Results:

- Select Centaur IMS
  - Lowest Drift
  - Compatible with Standard 1553 I/O
  - Low Weight
  - Uses state-of-the-art technology (ring laser)



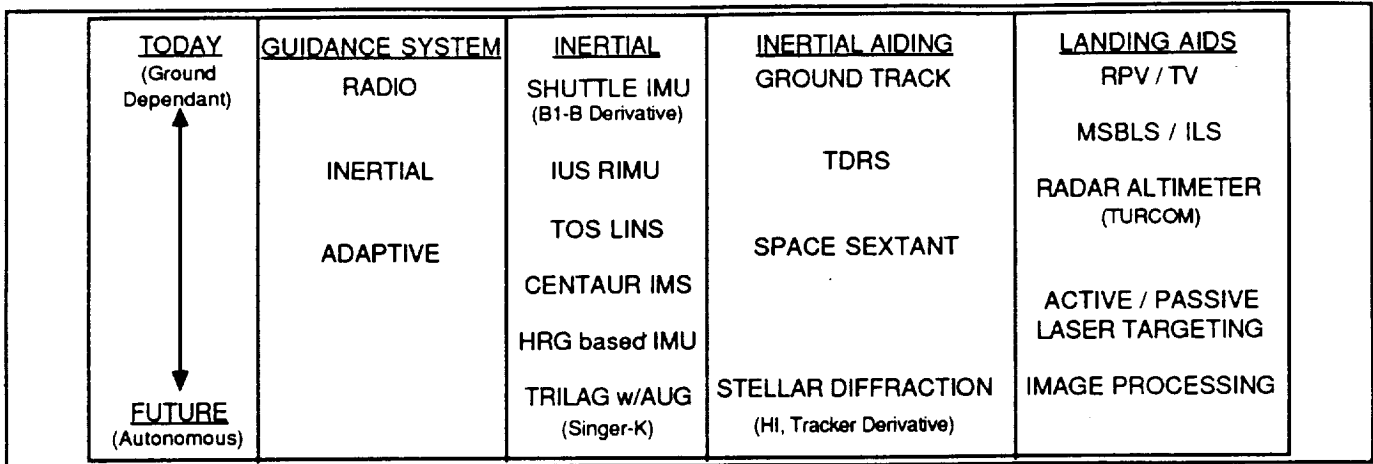


FIGURE 3.3-1. GUIDANCE &amp; NAVIGATION TECHNOLOGIES

Criteria Unit	Year available	3 sigma performance		Compatibility	Weight (lbs)	Cost	Notes	Risk	Rating
		gyro drift (deg/hr)	accel s/f** (ppm)						
Shuttle IMU	now	.045	TBD	shuttle unique	56	TBD	gimballed	Low	Good
IUS RIMU	now	.029	41	IUS unique	92	TBD	strapdown redundant	Low	Good
TOS	now	.09	200	1553 compatible	35*	TBD	strapdown	Low	Good
Centaur IMS	1990	.006	92	1553 compatible	40	.8M	strapdown	Low	Best
HRG based INU	1995	.0009	TBD	TBD	TBD	TBD	strapdown	Moderate	Good

\* Estimate  
\*\* Scale Factor

FIGURE 3.3-2 TECHNOLOGY MATRIX: INERTIAL MEASUREMENT UNIT

### 3.4 Engine Interface Unit (EIU) Replacement

The feasibility of replacing the current Shuttle Engine Interface Unit (EIU) with a modified Remote Voter Unit (RVU II) was investigated for the SDV-2ES (Shuttle C).

#### 3.4.1 EIU Description

Figure 3.4.1-1 is a functional block diagram of the EIU that shows the processes that would have to be duplicated by the RVU II. Figure 3.4.1-2 shows the EIU interfaces and describes their functions and characteristics. Figure 3.4.1-3 depicts the data flow between the Shuttle General purpose Computers, (GPCs), and the Main Engines. The EIU transmits commands from the Orbiter GPCs to Main Engine Controllers. When data and status are received by the EIU, the data is held in a buffer until an orbiter computer request for data is received by the EIU.

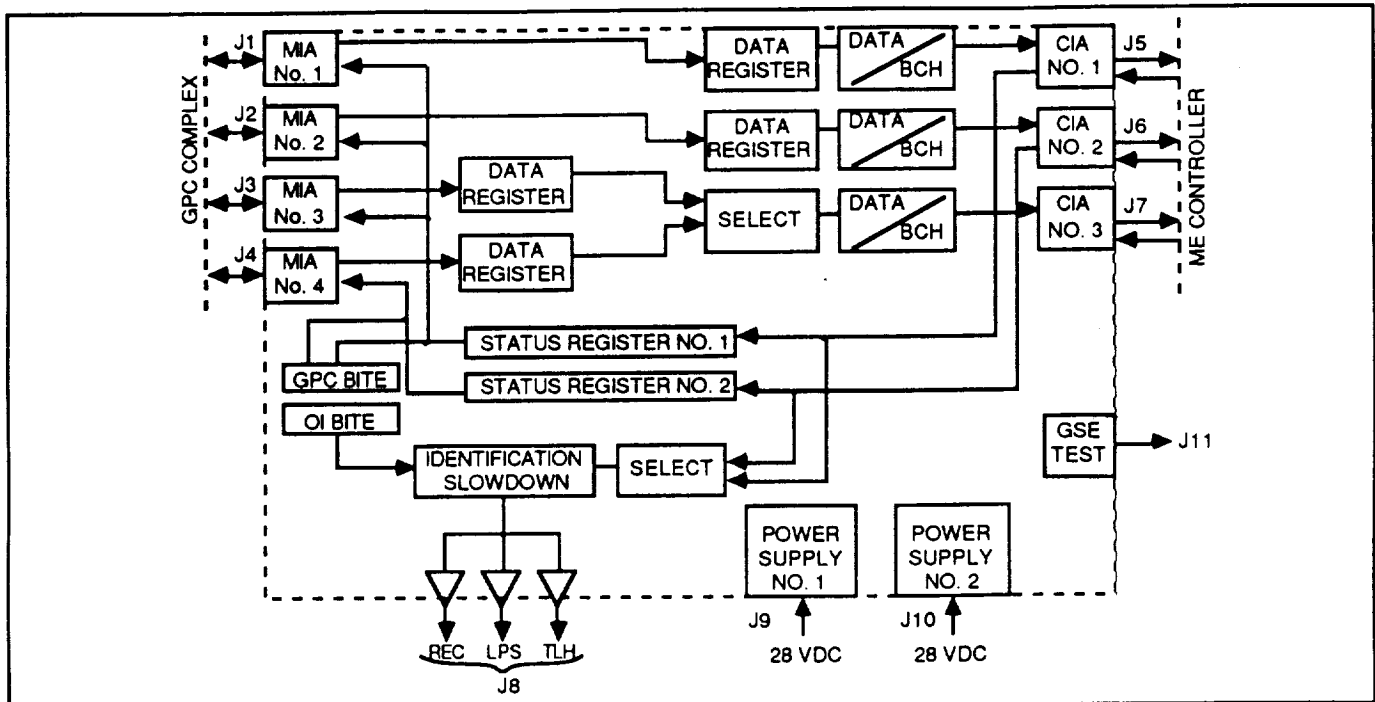


FIGURE 3.4.1-1 EIU FUNCTIONAL BLOCK DIAGRAM

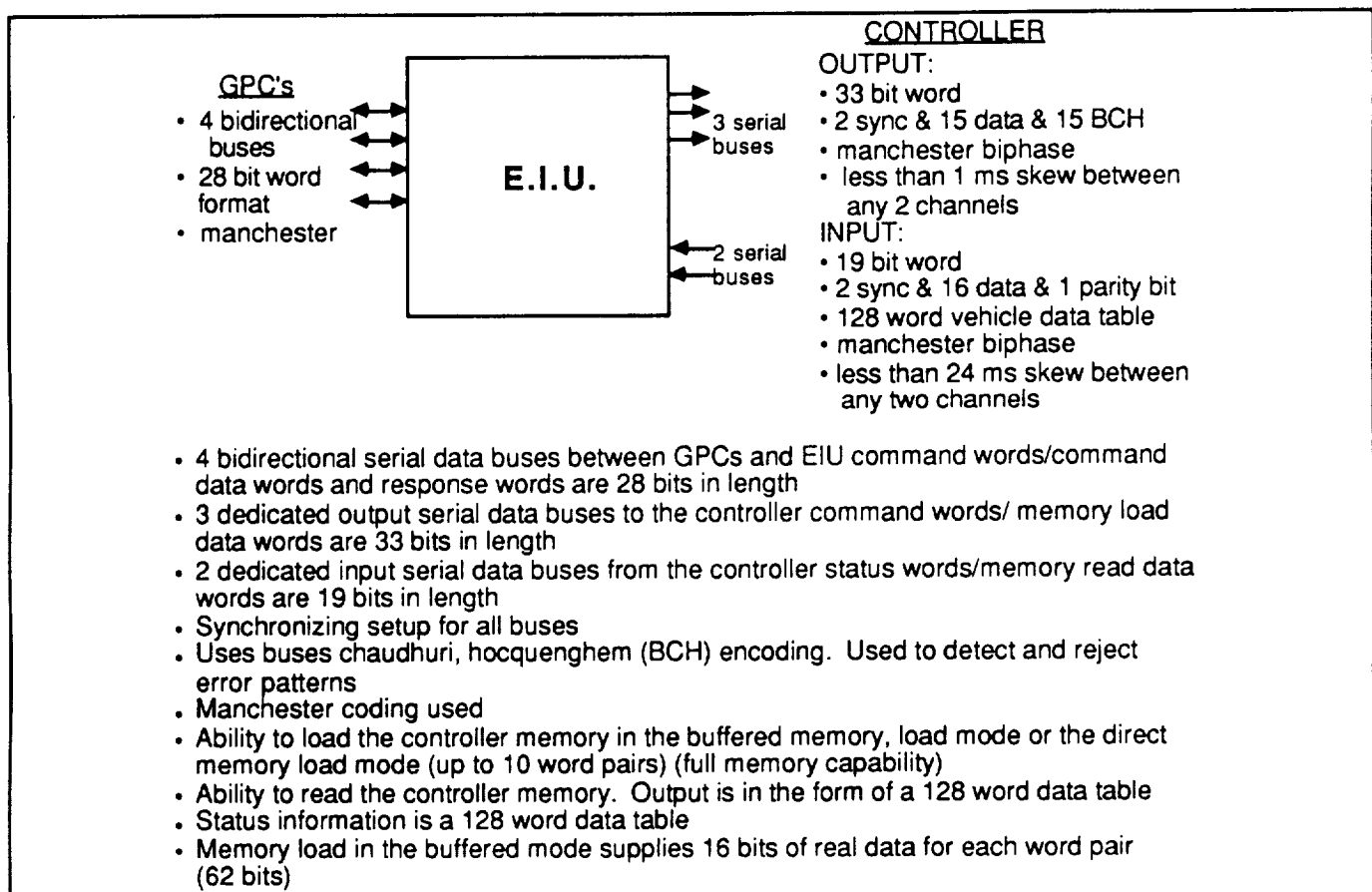


FIGURE 3.4.1-1. EIU INTERFACE DEFINITIONS

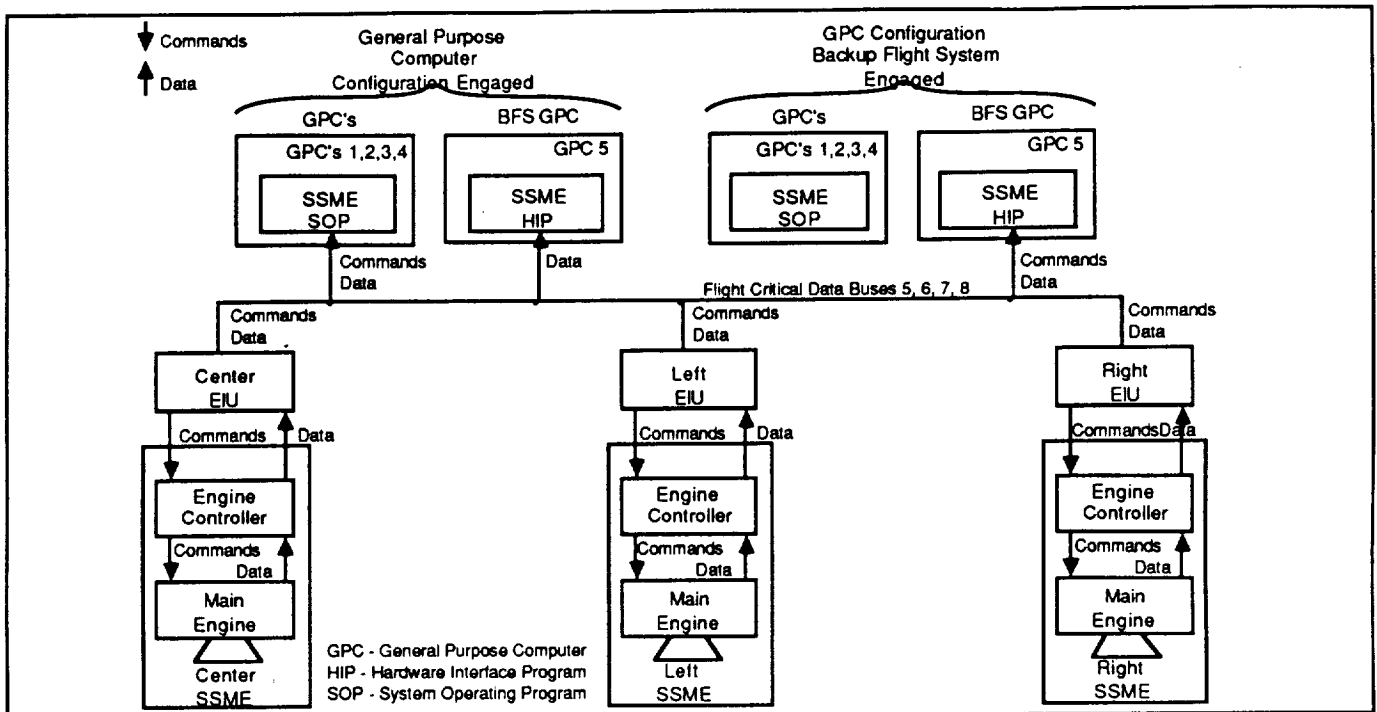


FIGURE 3.4.1-3. EIU DATA FLOW

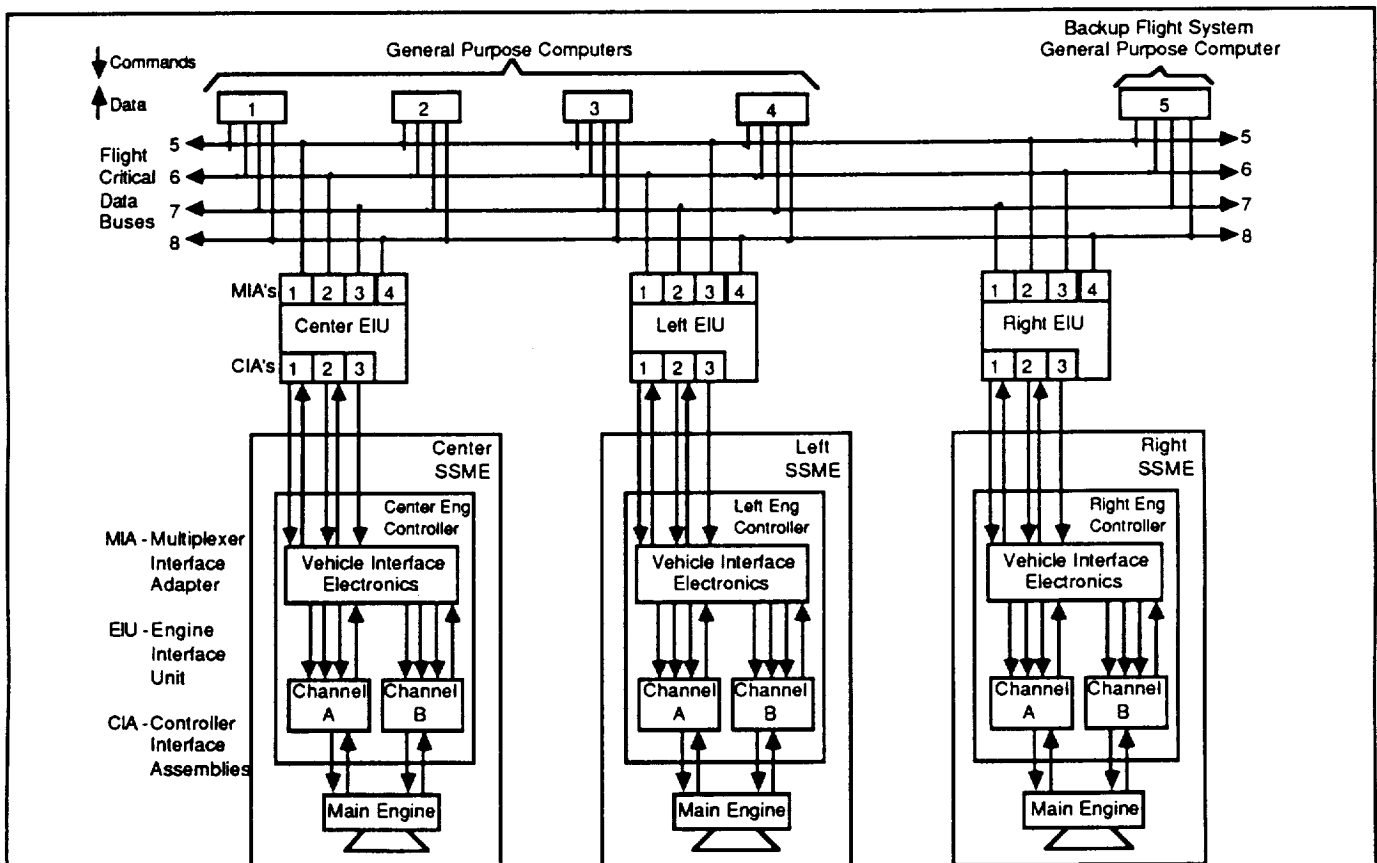


FIGURE 3.4.1-4. EIU BUS INTERFACES

Figure 3.4.1-4 shows the EIU bus interfaces, while figure 3.4.1-5 summarizes the results. Though future plans point to simpler engine control requirements, the current assumptions, of a total functional replacement for the SSME EIU didn't prove to be economically feasible. Notable, however, is that this study lead to investigation of RVU replacement of the Orbiter MDMs and RJD in the SDV-2ES avionics system. This in turn lead to the Shuttle C Option C avionics configuration. The Concept Definition Section contains this design.

	RECURRING COSTS	RECURRING OPER. COSTS	NON-RECURRING COSTS	PERFORMANCE MIN REG	PERFORMANCE GROWTH	RELIABILITY	RISK FACTOR
RVU II	SAME	same as other units	SAME	HIGH	HIGH	HIGHER	HIGH
EIU	SAME	unique unit & test	SAME	HIGH	LIMITED	LOW	LOW

• THE ABOVE ARE RANKED IN ORDER FROM HIGHEST TO LOWEST  
• NO ADVANTAGES IN GOING WITH THE RVU II

NOTE: Reduced Engine Control Requirements may alter conclusion.

**FIGURE 3.4-1. RVU II-EIU TRADE STUDY RESULTS**

### 3.5 Flight Control Actuators

The large Thrust Vector Control, (TVC) actuators proved to be the major area of concern in the developing area of Flight Control Actuators. Mid and Far Term vehicles will employ significantly more engines. The five primary ascent engines of the Shuttle will give way to clustered engine configurations using 14 to 20 engines on some future applications. The impact to ground processing and maintenance look to be intolerable if hydraulic actuators are retained. Electromechanical and Hydrostatic actuators present a better solution. Large EMAs, of the 50+ Horsepower range required, are still in development. Though control system design is adequate, development is needed in the power supply and distribution system areas. Figure 3.5-1 shows the three types of actuators investigated.

Recommendations included the retention of hydraulic actuators on near-term vehicles that still had relatively few engines. Design provisions should be made, even on these vehicles, for replacement with EMAs in the future. Emphasis on EMA and ancillary system development was felt to be imperative in light of the potential savings in maintenance, production and ground operations costs. Performance gains were felt possible, particularly in reusable, clustered engine configurations. Here the potential weight savings and increases in system reliability are significant.

#### 3.5.1 Recommendations

Select hydraulics until EMA technology matures. Reasons include:

- Currently in place
- Reliable and Flight Proven
- Does not require additional power supplies.

Select EMA in the near future. Reasons include:

- Less maintenance

- Future decrease in production costs
- Reduction in ground operations, and
- Less weight.

	Compatability	Availability	Risk	Cost	Performance	Rating
HYDRAULICS	EXCELLENT	NOW	LOW	LOWEST	GOOD	BETTER
ELECTROMECHANICAL	POOR	NEAR*	HIGH	HIGHER	GOOD	GOOD
ELECTROHYDROSTATIC	POOR	NEAR*	HIGH	HIGHEST	GOOD	GOOD

\*LABORATORY PROTOTYPE MODELS

	HYDRAULIC	EMA	EHA
NEAR/INITIAL	◇		◇
INTERIM	◇		◇
FAR TERM	◇	◇	
GROUND USE	◇	◇	◇
TEST LAB	◇	◇	◇

FIGURE 3.5-1. TECHNOLOGY MATRIX: ACTUATORS

### 3.6 Vehicle Power

The HLCV short duration missions seemed to dictate from the start that batteries rather than fuel cells would be the logical choice. A number of batteries were examined, along with a generic fuel cell, for near and far term applications. Figure 3.6-1 shows the general results. The analysis pointed to Lithium Thionyl Chloride as the best primary battery with Zinc Silver as a good back-up source. Fuel cells were shown to become more viable on long duration missions.

Power Distribution System designs were also explored. High and low voltage DC systems were compared with AC systems whose frequencies ranged from 400 Hz to 20 KHz. The standard 28 VDC system was shown adequate for near term designs. When EMAs are integrated into the HLCV era vehicles, a complete in depth reappraisal must be done.

#### 3.6.1 Power Distribution

Three major types of distribution are:

- 28 VDC Distribution
- High voltage distribution (270 VDC)
- AC Voltage distribution (400 Hz - 20 KHz)

**Results:**

- Lithium thionyl chloride batteries are recommended for all three versions of HLCV for short duration missions
- Zinc silver batteries will serve as a backup source in case problems develop with the prime batteries
- Trade off fuel cells vs. batteries for missions of longer duration

**Recommendations:**

- 28 VDC distribution system is recommended for HLCV systems
- Will trade-off distribution system for HLCV when EM actuators are used

	Compatability	Availability	Risk	Cost	Performance	USE			Rating
						Air	Ground	Lab	
Li/SIOCl <sub>2</sub>	Good	Near	Low	Low	Excellent	√			Excellent
Li/SO <sub>2</sub>	Good	Now	Moderate	High	Very Good	√			Good
Zn/AGO	Good	Now	Low	High	Good	√			Good
Li/V <sub>2</sub> O <sub>5</sub>	Good	Now			Good	√			Acceptable
Ma/MNO <sub>2</sub>	Good	Now	High		Moderate	√			Poor
Zn/HGO	Good	Now	TBD	High	Moderate	√			Acceptable
Zn/MnO <sub>2</sub>	Good	Now	Low	High	Low	√			Acceptable
Ni/Cl	Good	Now	Very Low	High	Low	√			Low
Li/FeCl <sub>3</sub>	Good	Now			Very Low	√			Poor
Fuel Cells	Good	Now	Low		Low	√			Low

**FIGURE 3.6-1. TECHNOLOGY MATRIX: POWER GENERATION****3.7 Ground Systems**

HLCV Ground Systems were viewed in terms of current practices and trends verses what far term trends best met program goals. The basic question of how much of the ground checkout and airborne checkout capability should be given to the vehicle avionics system had to be addressed. The use of Ground Systems for more than basic vehicle checkout and launch is gaining favor.

Figure 3.7-1 summerizes some of the established Ground System requirements. Figure 3.7-2 identifies those ground processing functions where automation via Ground Systems would be beneficial.

**3.7.1 Current Ground Systems**

To meet the IOC for the initial reference vehicle, a currently available Ground System must be adapted to meet the reference vehicles checkout and launch processing requirements. The two systems considered were the Titan Centaur Computer Controlled Launch System,

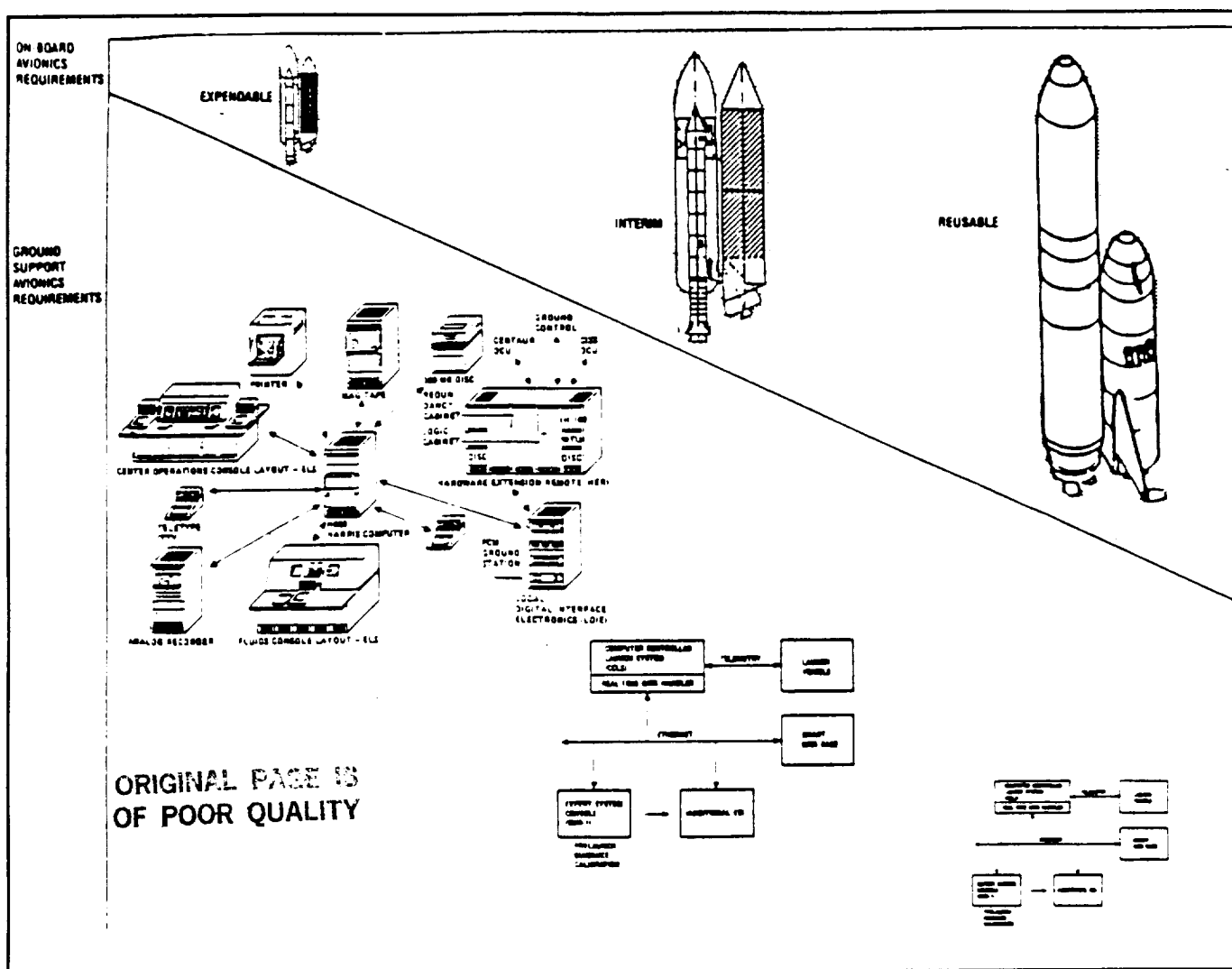
(CCLS). and theSpace Transportation System Launch Processing System, (LPS). The following is a brief summary of CCLS and LPS applicability.

CCLS

- To use CCLS at both launch pads would require modifying both areas at an unknown cost.
- CCLS can monitor around 1,100 downlink telemetry measurements
- The third or final version (reusable) of HLCV would probably overtax the capability of CCLS
- CCLS is cheaper to operate and maintain than LPS

**LPS**

- LPS is already in place at launch pads 39A and 39B
- LPS has a greater telemetry downlink capability than CCLS
- The reusable version of HLCV would benefit from the greater monitoring and control capability of the system
- LPS has higher operating cost than CCLS



### FIGURE 3.7-1. ESTABLISHED REQUIREMENTS

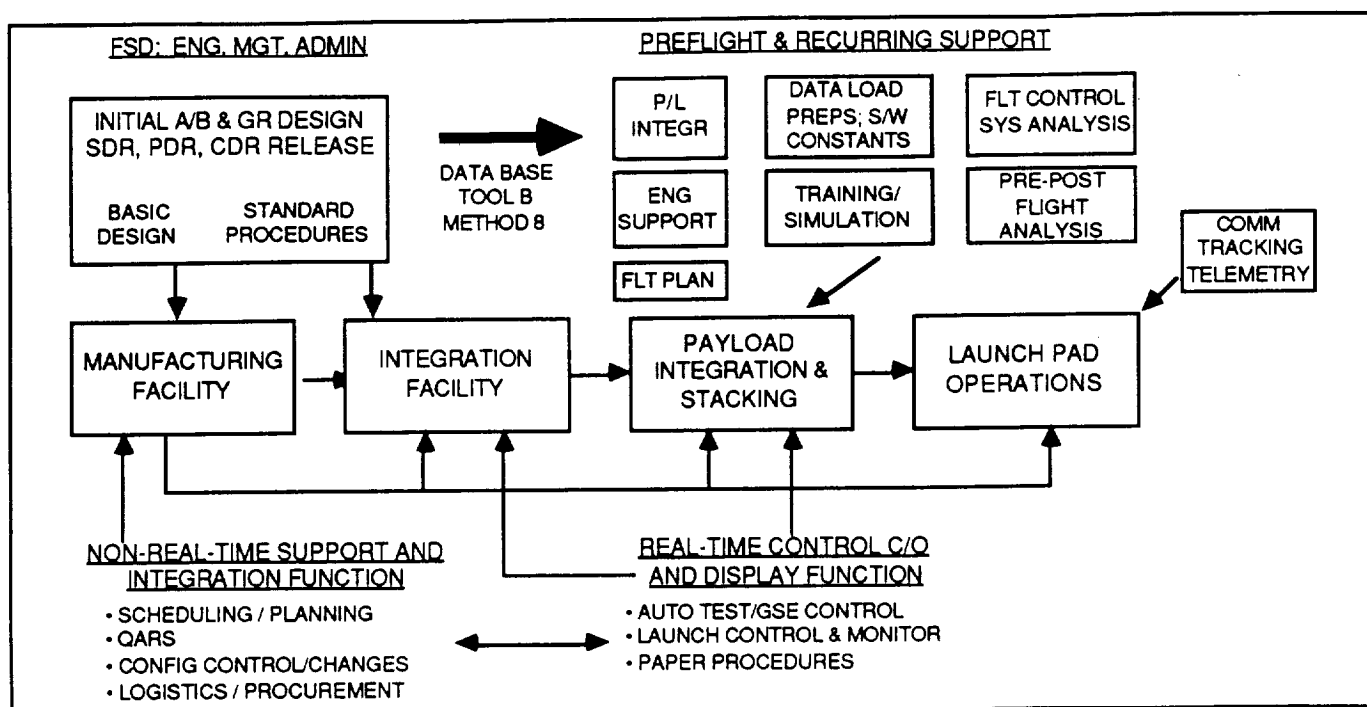


FIGURE 3.7-2. THE OPERATIONAL FUNCTIONAL FLOW IDENTIFIES AUTOMATION OPPORTUNITIES

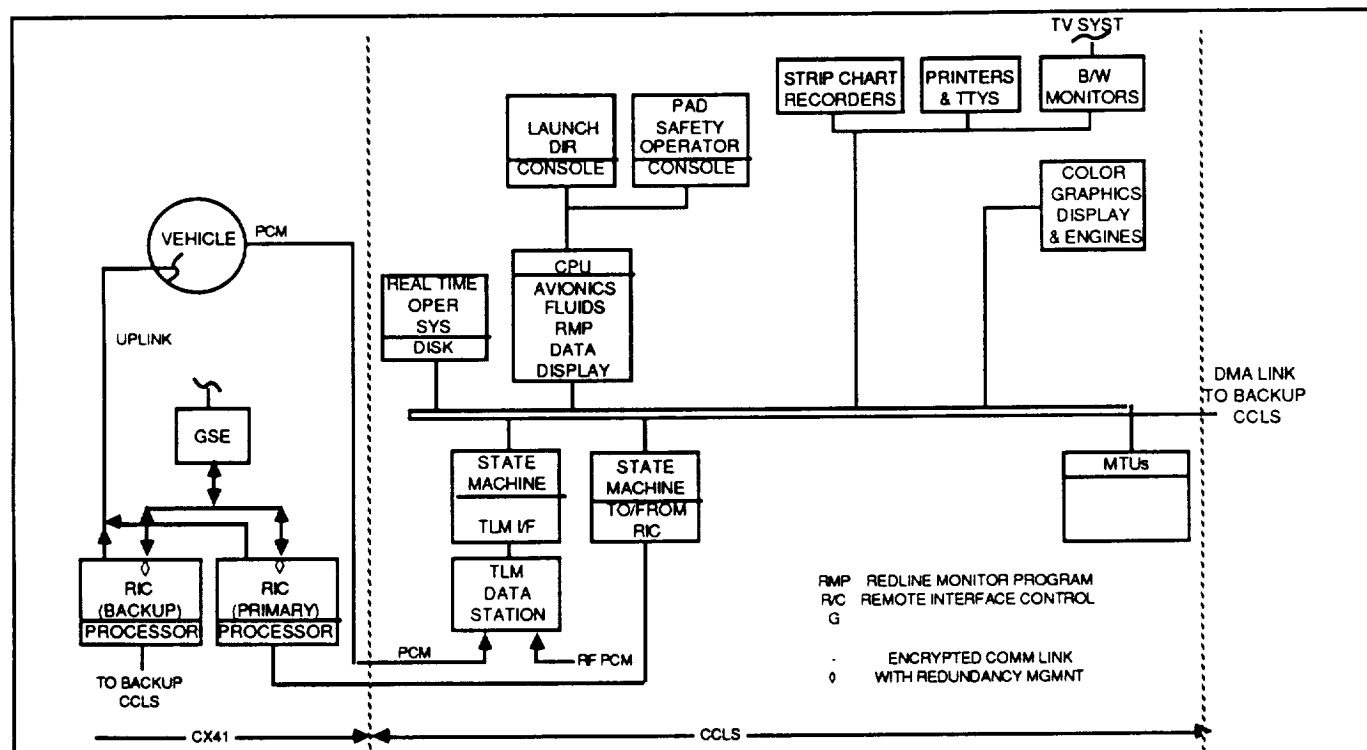


FIGURE 3.7.1-1. CCLS

Figures 3.8.1-1 and 3.8.1-2 show the CCLS and LPS functional block diagrams. Figure 3.8.1-3 compares the two current systems and an advanced Network based, distributed



system using five criteria. The LPS was chosen for Phase 1 use primarily on a compatability basis.

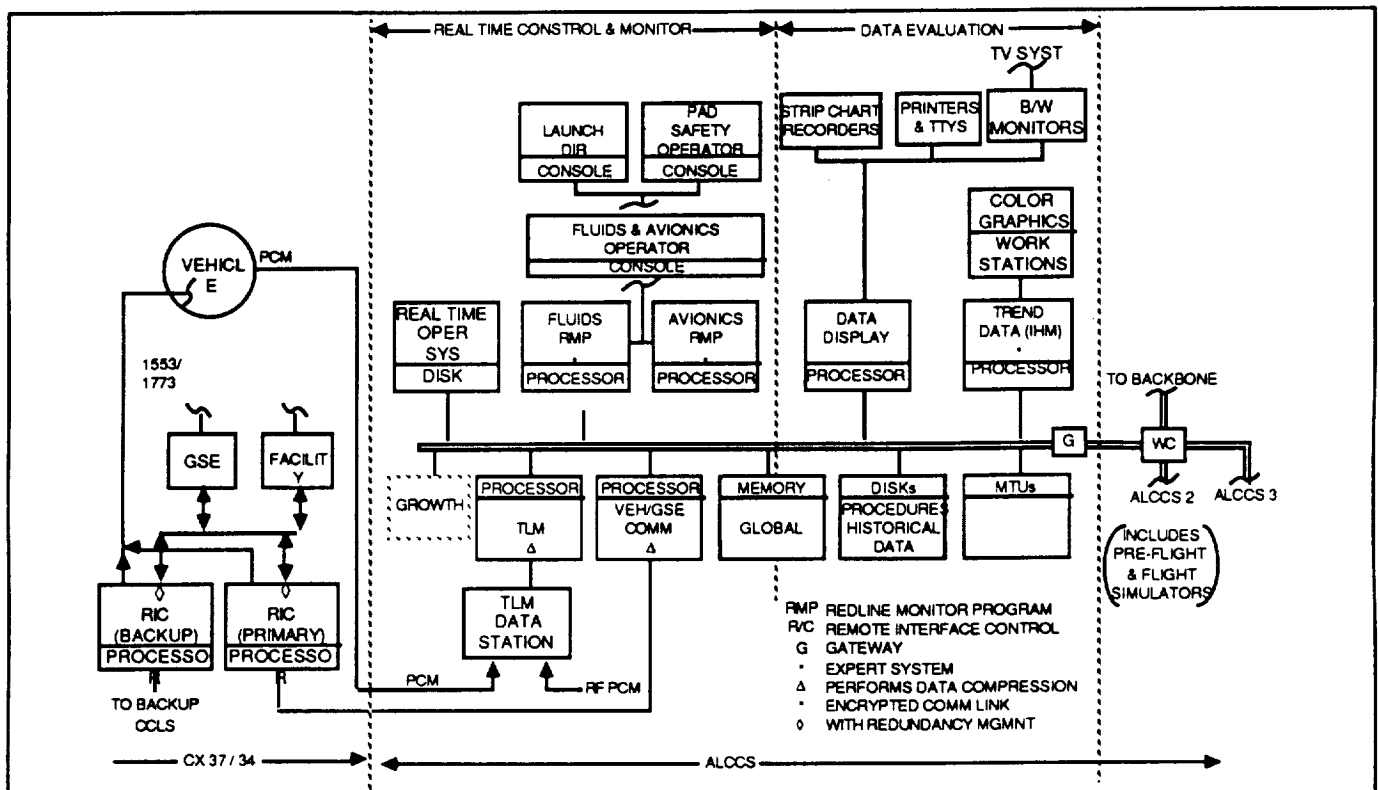


FIGURE 3.7.1-2. PRELIMINARY CONCEPT ADVANCED LAUNCH CONTROL COMPUTER SYSTEM

	Compatability	Availability	Risk	Cost	Performance	USE			Rating
						Air	Ground	lab	
CCLS	Poor	Now	Low	Lower	Good		✓	✓	Good
LPS	Good	Now	Low	Higher	Good		✓	✓	Better
NETWORK	Fair (Evolution)	Moderate	Moderate	Highest	Best		✓	✓	TBD (interim or optimum)

FIGURE 3.7.1-3. TECHNOLOGY MATRIX: GROUND SYSTEMS

#### Recommendations:

- LPS is recommended as the main Launch Support System for the Near Term HLCV (SDV-2ES)
  - LPS was designed to support the Shuttle
  - HLCV (SDV-2ES) will maintain Shuttle ground interfaces (H/W & S/W)
- LPS is already in place and functional
  - HLCV (SDV-2ES) ground and launch processing software will be a subset of current Shuttle software
- Trade Ground System Evolution
  - Near Term additions vs. Far Term vehicle autonomy

### 3.8 System Architectures

Vehicle and Ground Based Testbed architectures were analyzed in the context of the Heavy Lift Cargo Vehicle study objectives. The HLCV functional requirements formed the basis for the selection criteria in both the hardware and software architectures.

#### 3.8.1 Vehicle Architectures

Figure 3.8.1-1 shows three of the fault tolerant system architectures considered and some of their more important characteristics. The three shown include an asynchronous, multi string system, a loosely coupled system with shared CPU, and a synchronous, fully distributed, system that featured an open architecture.

Figure 3.8.1-2 shows an example of an MPRAS, (Multi Path, Redundant Avionics Suite), type architecture. The MPRAS type architectures are being considered for use in the Advanced Launch System, (ALS) because, in part, of their ability to include Integrated Health Monitoring, (IHM), and Expert System technology.

The Asynchronous system was chosen for the Phase 1 HLCV system for several reasons. Availability, expansibility, performance and cost effectiveness were the primary factors that swung the choice from a Shuttle Orbiter based system.

The MPRAS architecture was chosen for the far term vehicles. The cost savings associated with the IHM and Expert System technology to be included with the MPRAS architecture is the subject of the following sections.

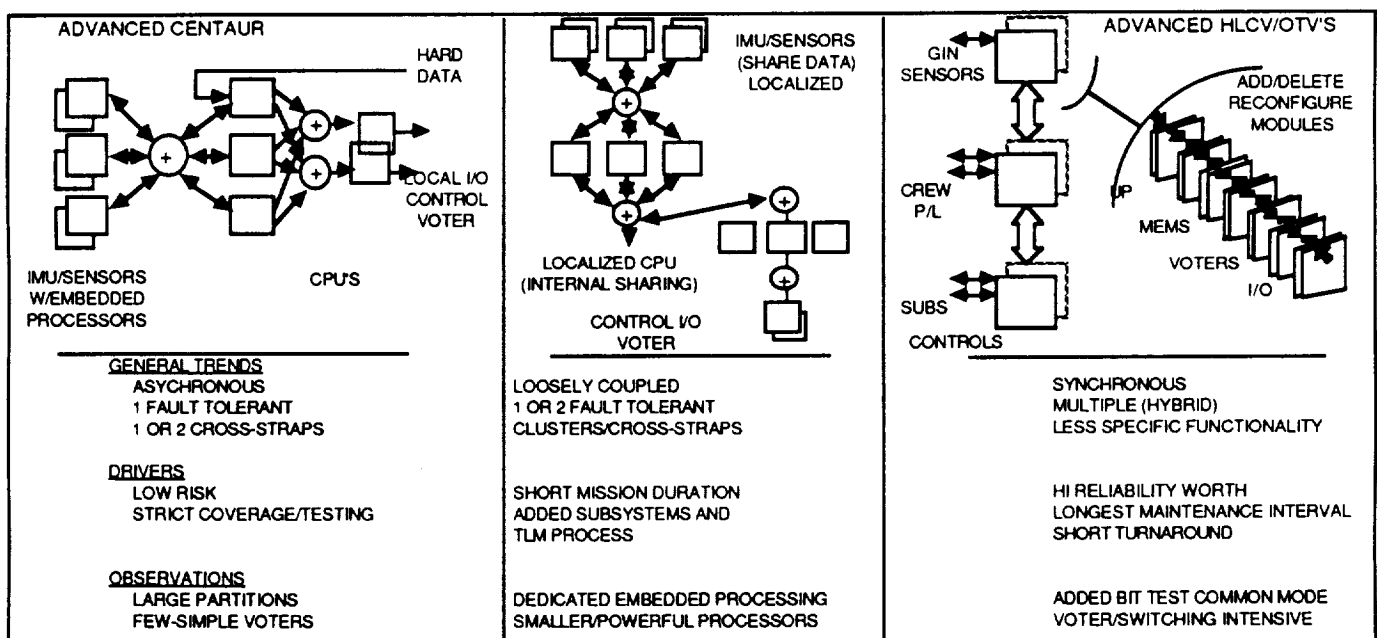


FIGURE 3.8.1-1. FAULT TOLERANT SYSTEM ARCHITECTURES

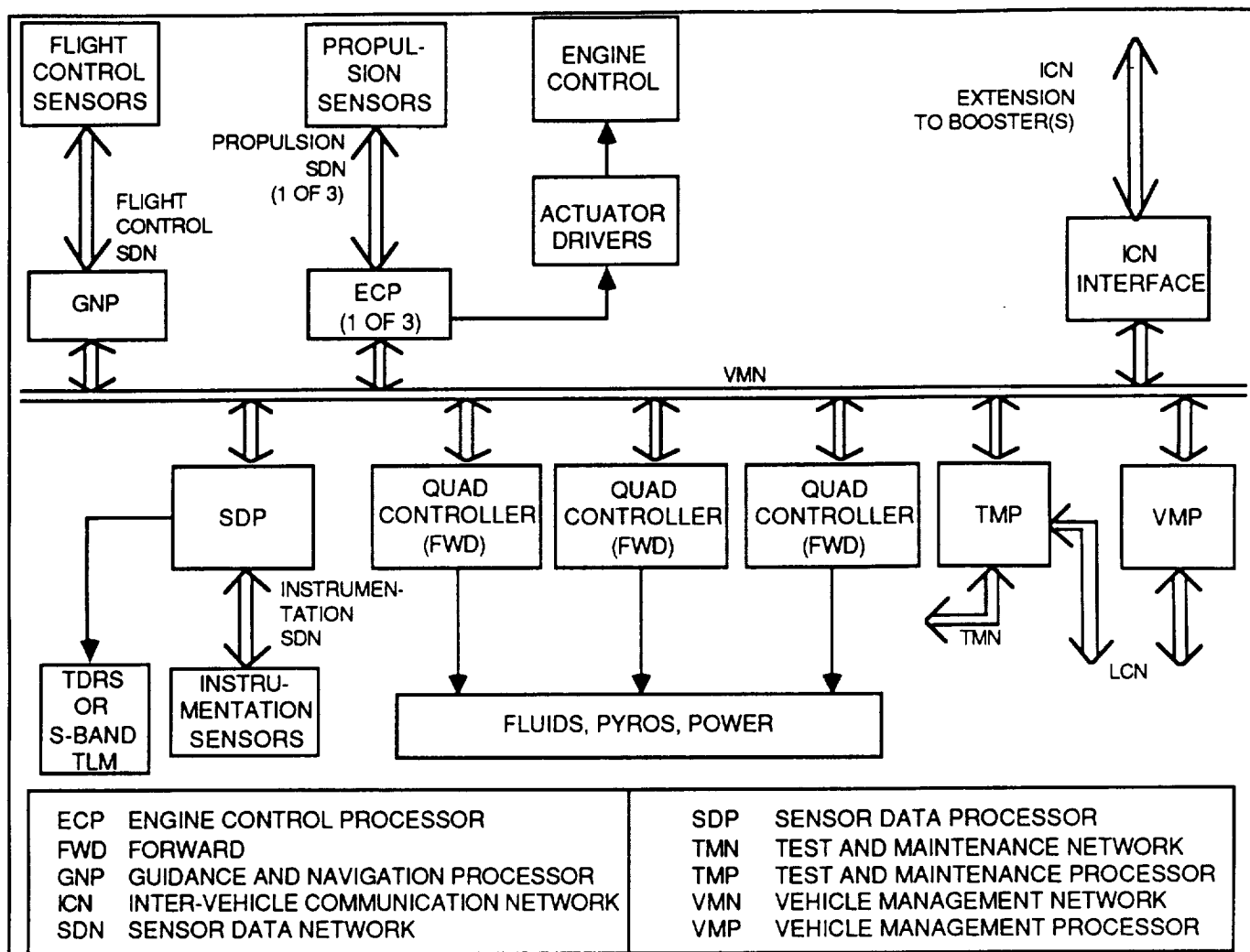


FIGURE 3.8.1-2. MPRAS

### 3.8.1.1 Integrated Health Monitoring

Figure 3.8.1.1-1 shows the goals of the IHM architectural designs. The GBT is designed to phase in the additional support for the IHM technologies during Phase 2. Some of the technologies are already scheduled for demonstration and are shown in Figure 3.8.1.1-2. Figure 3.8.1.1-3 shows some areas in which IHM can reduce the costs during testing.

**GOALS for INTEGRATED HEALTH MONITORING (IHM):**

- **IHM'S GOAL IS TO REDUCE SYSTEM COST AND SUPPORT HIGH LAUNCH RATES**
  - REDUCE TURN-AROUND TIME FOR LAUNCHING A VEHICLE
  - LOWER COSTS ASSOCIATED WITH TESTING AND DATA ANALYSIS
  - REDUCE PRE-FLIGHT COSTS
- **REDUCE TURN-AROUND TIME FOR LAUNCHING A VEHICLE**
  - FASTER TURN-AROUND ON FLIGHT FAILURES
  - REDUCE VEHICLE CHECKOUT TIME
- **LOWER COSTS FOR TESTING AND DATA ANALYSIS**
  - EFFICIENT, AUTOMATED TESTING
  - AUTOMATED DATA ANALYSIS AND TRENDING
- **PRE-FLIGHT COST REDUCTION**
  - REAL TIME ANALYSIS FOR FAULT TOLERANCE
  - IMPROVED VEHICLE TESTING FOR HIGHER RELIABILITY
  - BETTER DATA ANALYSIS FOR HIGHER RELIABILITY
  - FASTER TURN-AROUND ON FLIGHT FAILURES

AUTO DATA ANALYSIS  
SMART BIT

SMART BIT  
AUTO DATA ANALYSIS

ONE ENGINE OUT  
SMART BIT  
AUTO DATA TRENDING  
AUTO DATA ANALYSIS

FIGURE 3.8.1.1-1 IHM GOALS

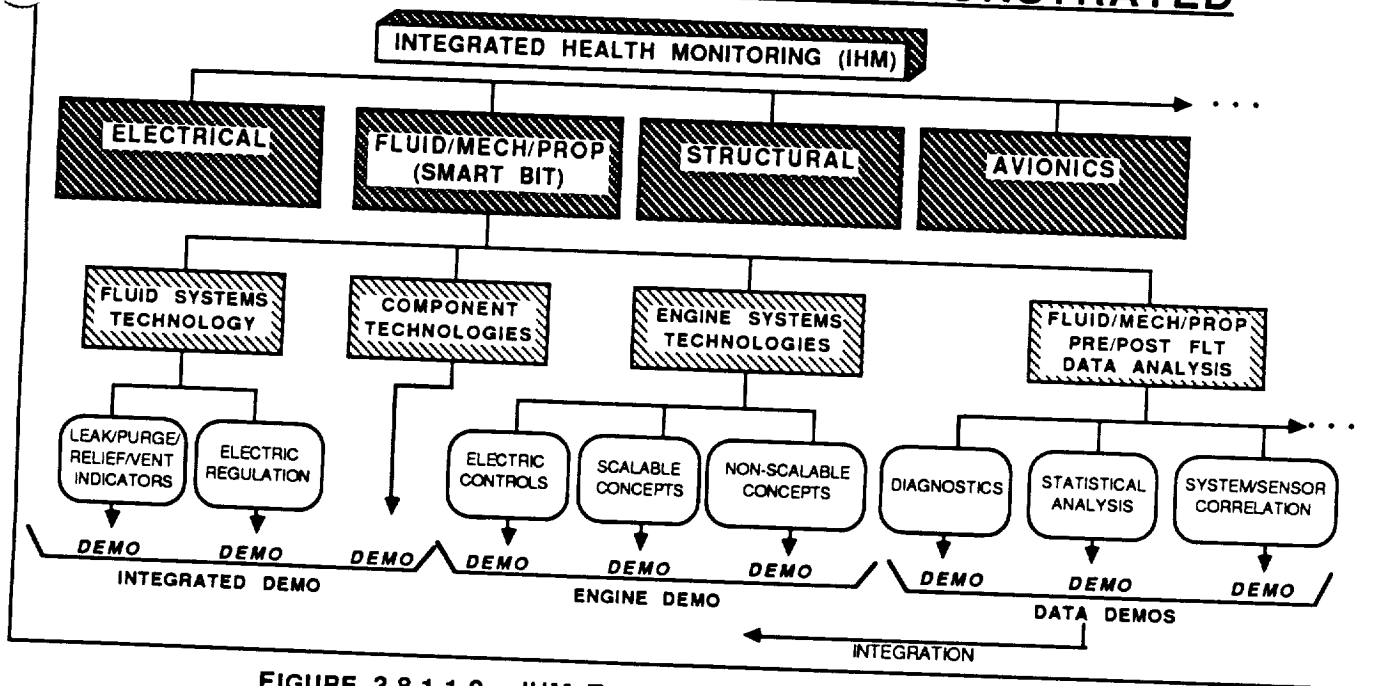
**IHM TECHNOLOGY TO BE DEMONSTRATED**

FIGURE 3.8.1.1-2. IHM TECHNOLOGY TO BE DEMONSTRATED

FUNCTIONAL AREAS	PLANNING & SCHEDULING	MONITORING, DIAGNOSTICS & ANALYSIS	EXAMPLES OF VIABILITY
FLIGHT PLANNING	<ul style="list-style-type: none"> <li>• Manifesting (Cargo &amp; Facilities)</li> <li>• Flight Design (trajectory design, ascent, descent, I-Loads, on-orbit contingency planning)</li> <li>• Vehicle / cargo flight software design and integration</li> </ul>	<ul style="list-style-type: none"> <li>• Expert system planner</li> </ul>	<ul style="list-style-type: none"> <li>• EXCABLE, shuttle payload cable router</li> <li>• Auto checkout / integration &amp; launch processing</li> </ul>
DATA LOAD PREP.	<ul style="list-style-type: none"> <li>• Product Integration Management Office (Reconfiguration of products, tools, etc...)</li> <li>• Plan for S/W &amp; H/W products and distribution</li> <li>• Automation of Flight Data File, (Checklists, etc...)</li> </ul>	<ul style="list-style-type: none"> <li>• Automated S/W integration &amp; testing with diagnostic analysis</li> </ul>	<ul style="list-style-type: none"> <li>• EXMIS, natural language I/F for shuttle mission support</li> <li>• Automation &amp; AI for space launch systems</li> </ul>
PAYLOAD INTEG.	<ul style="list-style-type: none"> <li>• Automated generation of PIP's, ICD's, Cargo Systems Manuals, etc...</li> <li>• Interface verification test (IVT's) operation</li> <li>• Scheduling &amp; documentation</li> </ul>	<ul style="list-style-type: none"> <li>• Automatic test &amp; diagnostic systems for integration verification</li> </ul>	<ul style="list-style-type: none"> <li>• SQUAL, study for expert system validation of shuttle flight loads</li> <li>• EXPDL, interprets &amp; validates S/W designs</li> </ul>
TRAINING & SIMULATION	<ul style="list-style-type: none"> <li>• Flight controller, crew, and customer training</li> <li>• Simulation S/W development and test</li> </ul>	<ul style="list-style-type: none"> <li>• Integral &amp; part time tasks trainers with self prompt &amp; auto eval.</li> <li>• Classroom applications for flight controllers, crew &amp; customers</li> </ul>	<ul style="list-style-type: none"> <li>• Expert pre-launch guidance calibration system</li> </ul>
COMM & TRACKING	<ul style="list-style-type: none"> <li>• Facility scheduling; (MCC, POCC's, LCC's)</li> <li>• Satellite tracking system scheduling; (GPS, TDRSS, GSTDN)</li> <li>• Space traffic control systems</li> </ul>	<ul style="list-style-type: none"> <li>• Development &amp; test of abort, recovery scenarios</li> <li>• Prediction of AOI, IOS times, contingency, real time communication sites</li> <li>• Fault monitoring</li> </ul>	<ul style="list-style-type: none"> <li>• Data compression for launch vehicle telemetry</li> </ul>
FLIGHT CONTROL	<ul style="list-style-type: none"> <li>• Rescheduling of flight critical operations</li> <li>• Launch operations</li> </ul>	<ul style="list-style-type: none"> <li>• Adaptive GN&amp;C system support</li> <li>• All sub-system monitoring &amp; control</li> <li>• Real time problem solving, malfunction procedures</li> <li>• Proximity operations, On-orbit robotics</li> </ul>	<ul style="list-style-type: none"> <li>• EXRMS, redundancy management for avionics systems</li> <li>• On-board performance monitor</li> </ul>
POST FLIGHT ANALYSIS	<ul style="list-style-type: none"> <li>• Post flight report distribution schedules</li> <li>• Telemetry optimization profiles</li> </ul>	<ul style="list-style-type: none"> <li>• Telemetry data analysis</li> <li>• On-ground data compression</li> <li>• Post flight report generation/ distribution</li> <li>• Trend analysis &amp; development</li> </ul>	<ul style="list-style-type: none"> <li>• Data analysis knowledge acquisition system</li> </ul>

FIGURE 3.8.1.2-1. AREAS IN WHICH EXPERT SYSTEMS WILL BE BENEFICIAL AND VIABLE.

### 3.8.1.3 GBT Architecture

The GBT software and hardware architectures evolved from the functional requirements, GDSS base of experience and selected analysis of available hardware and software. Figure 3.8.1.2-1 summarizes the GBT functions. The architecture must accommodate these functions in harmony with the GBT philosophy and objectives.

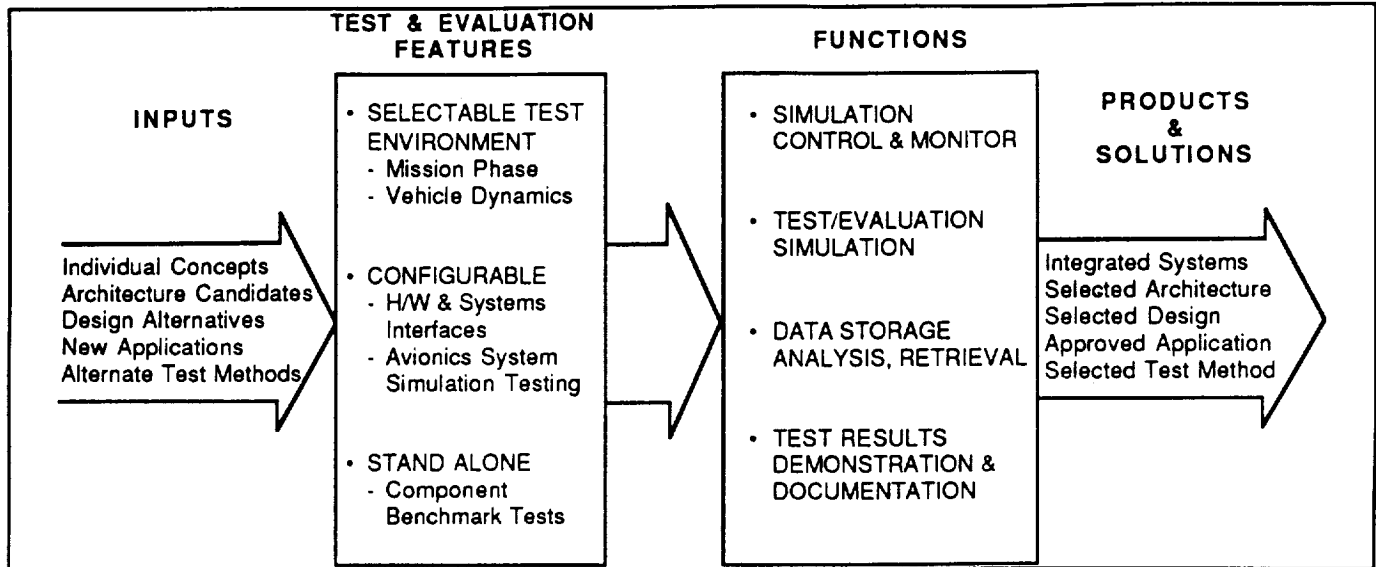


FIGURE 3.8.1.3-1. GBT FUNCTIONS

### 3.9 Data Buses & High Speed Networks

Closed-loop, real time, high fidelity simulations are basic to GBT success. The proper selection of data busses and high speed networks for data transfer and sharing between GBT elements not only required establishment of throughput but also a survey of currently available products. Figure 3.9-1 shows the four basic types of busses in the GBT. Phase 1 bus selection includes 1553 for the vehicle bus, ProNet 80 for the communications and control bus and VME Bus for the DMA bus.

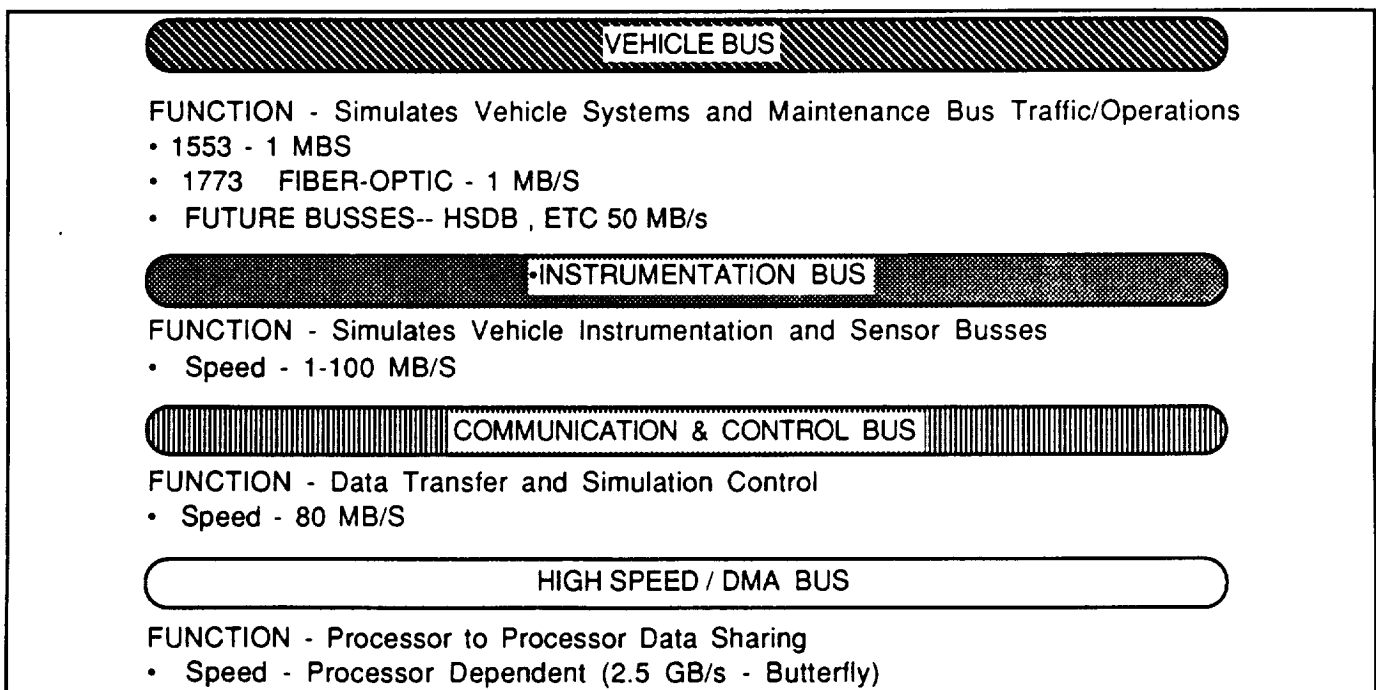


FIGURE 3.9-1. GBL BUS CLASSIFICATIONS

### 3.10 Instrumentation - Data Acquisition Technologies

The following outline lists the architectural features of a current avionic instrumentation system in launch vehicles:

- Digital Interfaces
  - Flight computer interface via data bus
    - ✓ One way data flow (computer ---> telemetry)
  - Spacecraft data interleaving is common
  - MIL-STD-1553 interface
  - Master Unit - remote unit interface typically on proprietary bus
- PCM Outputs
  - Tailored for specific application
  - Error detection/correction coding (i.e., Reed Solomon/Convolutional)
- Piece parts
  - S-level parts are not readily available for some applications
    - ✓ Gate arrays
    - ✓ Phase lock loop
    - ✓ EEPROMS
- Signal Conditioning
  - Software programmable gains and offsets
  - Multiplexed signals share signal conditioner circuitry
  - Multiplexed transducer excitation
- Digital Signal Processing
  - Low pass (anti-aliasing) filtering
  - Power spectral density (PSD)
  - Fast fourier transformer (FFT)
  - Transient recording
- Control Logic
  - May be processor based or hard logic driven
  - Extensive use of gate arrays
  - EEPROMS used for remote programming
  - Limited radiation/single event upset hardening

#### Data Acquisition Technologies - Near Future

- Digital Signal Processing
  - Programmable general purpose DSP modules
  - Data compression
  - On-board data analysis
  - Built-in-test
- Control Logic
  - Most systems will use some form of processor
  - System can be configured with "dumb" or "smart" remote units

- Digital Interfaces
  - Redundant reconfigurable MIL-STD-1553 data bus interface
  - Two way data communication with flight control system
- PCM Outputs
  - Encryption on a chip eliminates need for external encrypter with interface unit

	Compatability	Availability	Risk	Cost	Performance	USE			Rating
						Air	Ground	Lab	
FDDI	Excellent	Near	Moderate	High	Excellent	✓	✓	✓	Excellent
HSDB		Near	Moderate	High	Very Good	✓		✓	Good
IEEE802.3	Acceptable	Now	Low	Low	Good		✓	✓	Acceptable
IEEE 802.4		Now	Moderate	Low	Good		✓	✓	Acceptable
IEEE 802.5		Now	Moderate	Low	Good		✓	✓	Excellent
1553	Excellent	Now	Very Low	Low	Poor	✓		✓	Good
1773	Excellent	Now	Low		Poor	✓			Acceptable

FIGURE 3.10-1. TECHNOLOGY MATRIX: DATA TRANSFER

## Recommendations:

- Select Fiber Distributed Data Interface (FDDI) or High Speed Data Buss (HSDB) for near term
  - Both use fiber optic media for high data rates, excellent EMI immunity, low signal loss, and low weight
  - Both are designed to be fault tolerant
    - ✓ The FDDI Standard System uses 4B/6B encoding techniques and the latest hardware technology to handle a 100 MBPS data rate
    - ✓ HSDB uses the Manchester encoding technique (which is 30% less efficient) and more readily available hardware to produce a 50 MBPS data rate
      - FDDI should be selected in multiple processor ring applications
      - Modifications to FDDI will be necessary for linear applications
      - For lower cost, near term, high speed linear applications, HSDB should be used

**3.10.1 GBT Instrumentation Systems Support**

The original concept of the GBT Avionics Hardware Testbed provided most of the required interface capabilities to support instrumentation system operational testing and evaluation. Lacking was the ability to fully evaluate the downlink data. The instrumentation segment was added to the GBT to permit end-to-end evaluation of HLCV telemetry systems. Section 6 describes the GBT architecture and the function of the instrumentation element.



### **3.11 GBT Main Processor Selection**

With the shift of emphasis to design of the GBT, selection of the primary lab processor took on added importance. The scope of the trade study used to determine the performance characteristics of this unit and the attendant survey of potential vendors required a special effort. A technical demonstration was conceived that would permit a performance comparison of those processors and their software tools thought capable of fulfilling the basic requirements. The test would involve tasks similar to those planned for the GBT and use programs supplied by both the customer and GDSS.

The initial selection process of potential processors considered about 20 candidates. Figure 3.11-1 shows some of the selection criteria and the candidates that fulfilled the criteria. The "paper study" was followed up with a head-to-head performance comparison. Three benchmarks were selected to evaluate the processors and their attendant software tools. The first benchmark was from MSFC and was a mature Fortran coded model of the SSME. The second was provided by GDSS and was a modular model of the ALS avionics system coded in "C". The third benchmarks were industry standards chosen by the participants.

The final phase of the tech demo has been extended to include additional processors for evaluation. A detailed review of the initial study and a complete analysis of the performance test results will be reported in the Final Report Addendum. Also included will be the analysis that lead to the ultimate selection of the Concurrent Goldrush series computer.

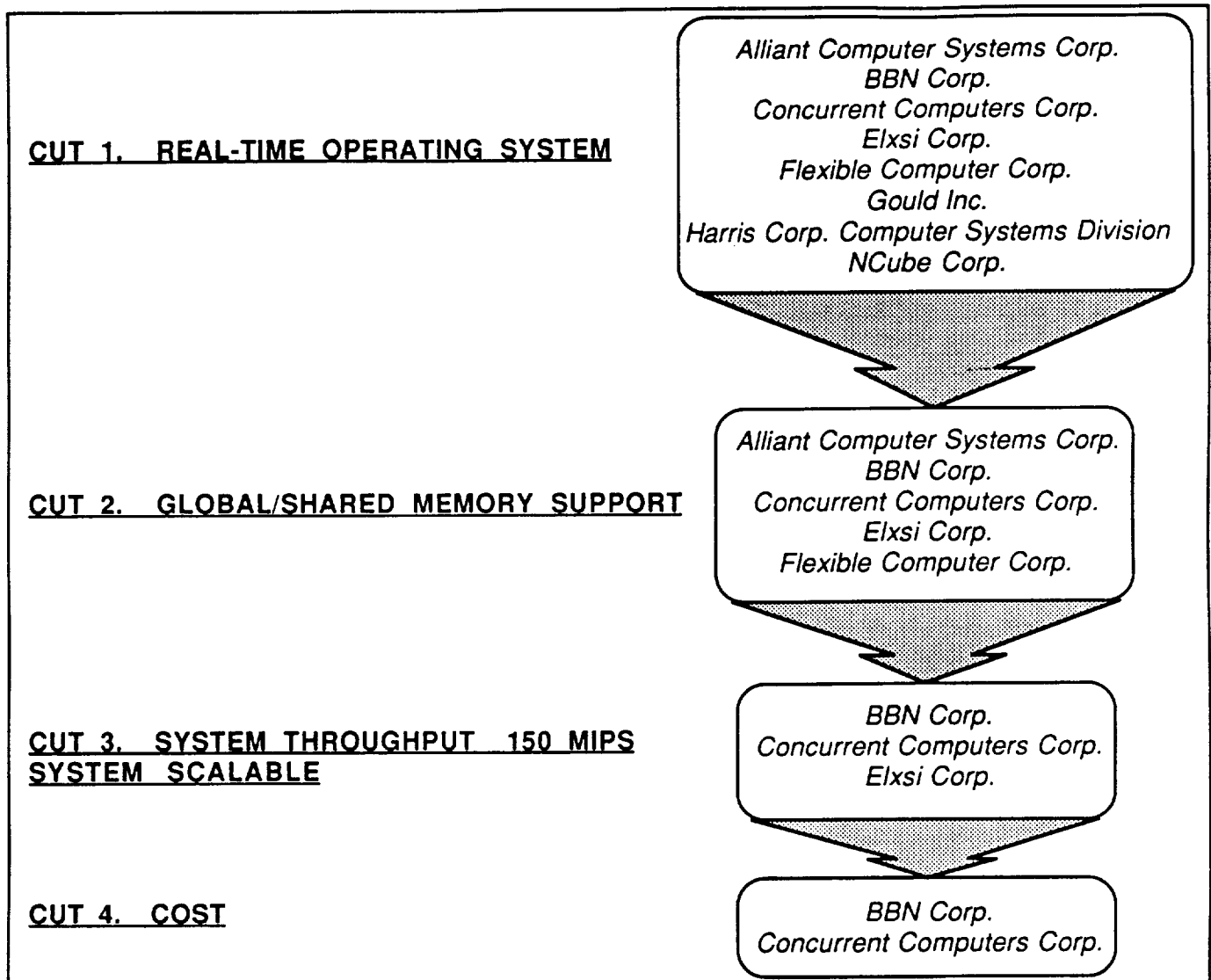


FIGURE 3.11-1. SELECTION CRITERIA/CANDIDATES

## 4.0 REQUIREMENTS

Section 4.0 identifies the Phase I GBT requirements and the vehicle support requirements from which they were driven. Phase II and full-up target phase driven requirements are covered only incidentally. A shift toward designing a phased GBT was directed by the customer after the reference HLCV avionics systems had been conceptually designed and sized sufficiently to determine the requirements of a supporting development and evaluation lab. This GBT would accommodate integrated, real time, testing and evaluation of generic HLCV era avionic systems and line replaceable units (LRU'S) To this end, a Preliminary Design Document (PDD) was generated that contained details of a Phase I GBT. The lab was structured for growth and sized with hooks for future phases. The core processor, as an

example, was initially sized to handle operations beyond the ascent, on-orbit maneuver and de-orbit of the Phase 1, Shuttle derived reference vehicle. The processor chosen can accommodate a Phase 2 vehicle and has planned expendability to easily accommodate vehicles beyond the far term, Target vehicles. The Avionics Hardware Testbed and its supporting software will also accommodate the growth of technology and handle all three phases of expansion.

#### 4.1 GBT Functional Requirements

The requirements to which the GBT must respond fall into three general categories:

**Program Driven** requirements include such things as vehicle dynamics, mission profile/timelines and vehicle avionic system architecture. The second general category, **Technology Driven** requirements, include design problem areas that are not meeting performance criteria or are limiting system efficiency or upgrade. The last general category of functional requirements is **Facility/Resource Driven** requirements. These requirements are related more to the physical aspects of the test facility itself and the limitations of the resource equipment used in testing.

#### 4.2 Program Driven Requirements

The GBT was conceived to provide support to new vehicle/spacecraft programs primarily before their respective Preliminary Design Reviews, (PDR's), or when the nature of the required support was beyond the capabilities of their local, dedicated facilities. Figure 4.2-1 outlines some of the requirements associated with these vehicles and their mission profiles. Some of the many program driven issues are:

- Inertial navigation unit must meet specification required to navigate to Space Station and dock within Space Station contract constraints
  - Axial closing velocity .2 fps max
  - Lateral velocity  $\pm .0$  fps
  - Angular velocity  $\pm .05$  deg/sec roll  
 $\pm .15$  deg/sec lateral
- Payload support required for Centaur G using payload GSE
- The Avionics system reliability and redundancy
- Support successful de-orbit (Phase II) with a planned ocean impact of surviving parts
- Use best of available, mature avionics components from STS and other applications where cost and risk effective

Vehicle	Shuttle C	ALS Core	ALS LRB	FRWB
Reusability	SRB's	None	BRM	Full Reuse
IOC	1995	1998	1998	2002
Engines	3 + 2 SRB	3	7	6 + 6 A/B
Man Rating	TBD	0.99981	0.99995	TBD
Reliability	Cargo carrier Prox OPS & De-orbit	Deorbit to ocean. FO/FS Manned Cargo	Sub-orbital FO/FS Manned Cargo	Return & Landing FO/FS Manned Cargo
Max Mission Duration	6-1/2 hours plus s.s ops	Core de-orbit T + 98 min.	1 + 162 seconds	Less than 1 hour
Mission/Year	Few	Many	Many	Many
Number of Vehicles	Moderate	Many	Many	Few
Integrated Systems	Separate LPS, GSE Prod C/O	UNIS for Integrated Data	UNIS	UNIS
Launch Processing	LPS	Expert System App	Expert Systems App.	Near Autonomous
P/L and Vehicle I/F's	Shuttle Bay Interface	None	None	None
Vehicle Management	Central computers O.S Command Uplink	Mission manager Expert Systems	Controlled from Core	Near Autonomous Manual Backup
Hendezvous & Docking	OMV Assisted	None	None	None
Data Flow	TBD Fairly low rate	GN&C 3 - <1 MBPS Instru 1 - 256 KBPS	Interface to Core	GN&C 3 - <10 MBPS Instru 1 - 320 KBPS
Processing	300 KOPS	GN&C 3 @ 3 MIPS ea Propulsion 3 @ 1 MIPS Instru 1 @ 3 MIPS Miscellaneous < 1 MIPS	Share core GN&C Propulsion 7 @ 1 MIPS ea Share core Instru Miscellaneous <1 MIPS	GN&C 3 @ 6 MIPS Propulsion 6 @ 1 MIPS Instru 1 @ 3 MIPS Imaging 10 MIPS Miscellaneous <2 MIPS

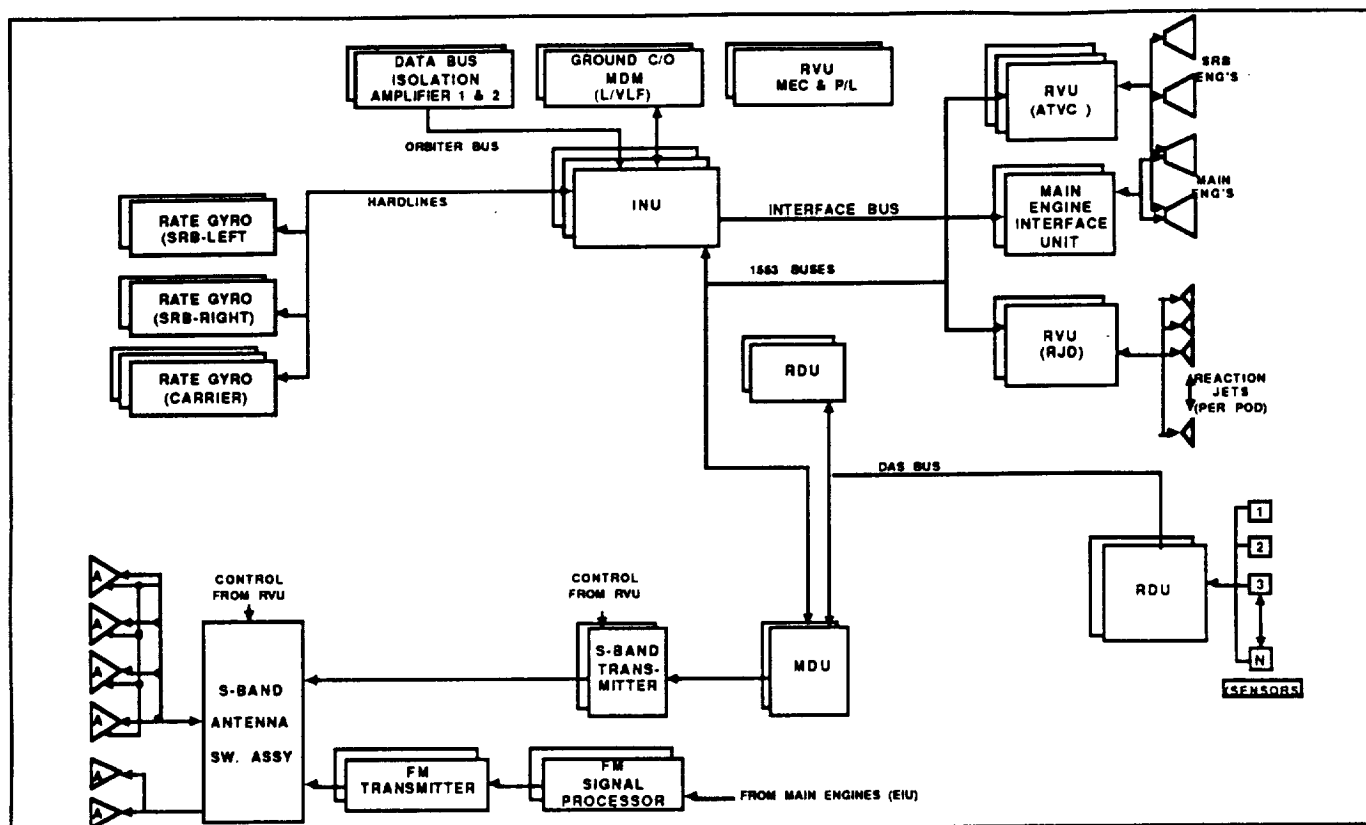
FIGURE 4.2-1 HLCV AVIONICS REQUIREMENTS

#### 4.2.1 Phase 1 (STV, Shuttle C, SDV 2ES)

The HLCV expendable booster, (SDV-2ES), Shuttle-C, and Space Transfer Vehicle (STV) developmental programs are the basis for the Phase 1 GBT functional requirements. Shuttle-C was agreed upon to serve as the forcing function for the Phase 1 lab. The functional block diagram for this three-string avionics system is shown in Figure 4.2.1-1. The Program requirements that drove the avionics system design are listed below.

##### Shuttle-C Program Requirements:

- First flight = 1994
- Low DDT&E and cost
- Maximum utilization of STS and other flight proven hardware systems
- Maximum utilization of existing STS test and launch facilities
- Simplified ground and flight operations
- 2-3 flights per year for 10 years (access impact of up to 6 flights per year)
- Unmanned cargo vehicle (manrated)
- Expendable cargo element
- Minimum performance of 100 LKB to 220 nm/28.5 degrees
- Minimum payload envelope of 15 x 60 feet
- 100% SSME power level
- High reliability and system resiliency
- Payload interchangeability with STS
- On orbit control and Space Station docking to utilize OMV to maximum extent possible.



**FIGURE 4.2.1-1. SHUTTLE-C AVIONICS BASELINE**

• VEHICLES

- PERFORM AVIONICS ANALYSIS/SIMULATION TO VERIFY RE-TEST AND RE-USE CAPABILITY OF FRWB AND BRM MULTI-MISSION AVIONICS
- LAUNCH PROCESSING AND VEHICLE MANAGEMENT
  - PROVIDE THE PROCESSING THROUGHPUT AND MEMORY CAPACITY FOR EXPERT SYSTEM APPLICATION DEVELOPMENT OF BOTH LAUNCH PROCESSING AND ON-BOARD MISSION MANAGER
- RENDEZVOUS AND DOCKING
  - PROVIDE A 3D DISPLAY PROCESSING CAPABILITY FOR SHUTTLE C CARGO CARRIER/ OMV/ SPACE STATION. PROVIDE A FUTURE CAPABILITY IF ALS CORE DEVELOPS THIS TYPE OF MISSION
- IOC
  - 1994 SHUTTLE C PROVIDE PROVISIONS FOR SIMULATING MODIFICATIONS TO EXISTING H/W AND S/W
  - 1997 ALS REQUIRES EXPENDABLE CAPABILITY AS ALS SOFTWARE IS EXPANDED
  - 2000 FRWB WIDE CAPABILITY
- MANRATING
  - SHUTTLE C CARGO CARRIER FO/FS FOR SPACE STATION PROXIMITY OPERATIONS. DIFFERENT CARGO CARRIER FOR INJECTION MISSIONS?
  - ALS CORE FO FOR DE-ORBIT, FO/FS FOR MANNED CARGO
  - FRWB FO/FS FOR FLYBACK AND LANDING. FO/FS FOR MANNED CARGO
  - HLCV GBT SIMULATE REDUNDANCY PROVISIONS TO MEET ABOVE GOALS
- ENGINE SYSTEM INTEGRATION
  - 3 SHUTTLE C, 10 TO 14 ALS FUTURE SYSTEMS
  - TVC ENGINE CONTROL INTEGRATION (~1 MIPS PER ENGINE)
  - SIMULATE ARCHITECTURE PARTITIONING FOR BRM RECOVERABLE AVIONICS

### FIGURE 4.2.1-2 PROGRAM DRIVEN ISSUES

DISCRIMINATING CHARACTERISTICS	DESIGN REFERENCE MISSIONS (DRM'S)			PERFORMANCE REFERENCE MISSIONS (PRM'S)	
	(1) UNMANNED SPACE STATION ASSY W/OMV	(2) ORBITAL DEPLOY	(3) SUB-ORBITAL DEPLOY	(1) POLAR LAUNCH FROM ETR	(2) POLAR LAUNCH FROM WTR
LAUNCH SITE	ETR	ETR	ETR	ETR	WTR
SECURE	NO	POSSIBLY	POSSIBLY	POSSIBLY	YES
INCLINATION	28.5'	28.5'-63.5'	28.5'	98.7'	98.7'
RENDEZVOUS & PROX OPS	YES	NO	NO	NO	NO
REFERENCE ALTITUDE	220 nmi	110 nmi	≥ 100 nmi	100 nmi	100 nmi
DOCK/BERTH	YES	NO	NO	NO	NO
ON-ORBIT STAY TIME	APPROX. 14 DAYS	1 DAY	UNSPECIFIED	≤2-1/2 HR	≤2-1/2 HR
CIRCULARIZATION	YES	YES	NO	YES	YES
PAYLOAD DEPLOYED	NO	YES	YES	YES	YES
PAYLOAD EXTRACTED	YES	NO	NO	NO	NO
MANNED PRESENCE	YES	NO	NO	NO	NO
MIXED CARGO	YES	POSSIBLY	NO	POSSIBLY	POSSIBLY
OMV	YES	POSSIBLY	NO	NO	NO
MINIMUM INJECTED WEIGHT @ REFERENCE ALTITUDE	100,000 LB	80,000 LB	100,000 LB	TBD	TBD
INSERTION	DIRECT	STANDARD	SUBORBITAL	UNSPECIFIED	UNSPECIFIED

FIGURE 4.2.1-3. SHUTTLE C MISSION REFERENCES

#### 4.2.2 Phase 2 (ALS Core, ALS Booster, SDV 2RS)

The Phase 2 IOC is set for August 1992. The Phase 2 GBT support capabilities will be extended to include the ALS Core and Booster, SDV-2RS, and the upgraded Shuttle-C. Since the ALS Core and Booster closely fit the SDV-2RS functional requirements, they were chosen for the reference vehicles for the Phase 2 GBT. Figure 4.2.2-1 through 4.2.2-3 show the ALS Core and Booster avionics systems and the associated vehicle processing requirements. Figure 4.2.2-4 associates the ALS Core throughput requirements with its design reference mission timeline.

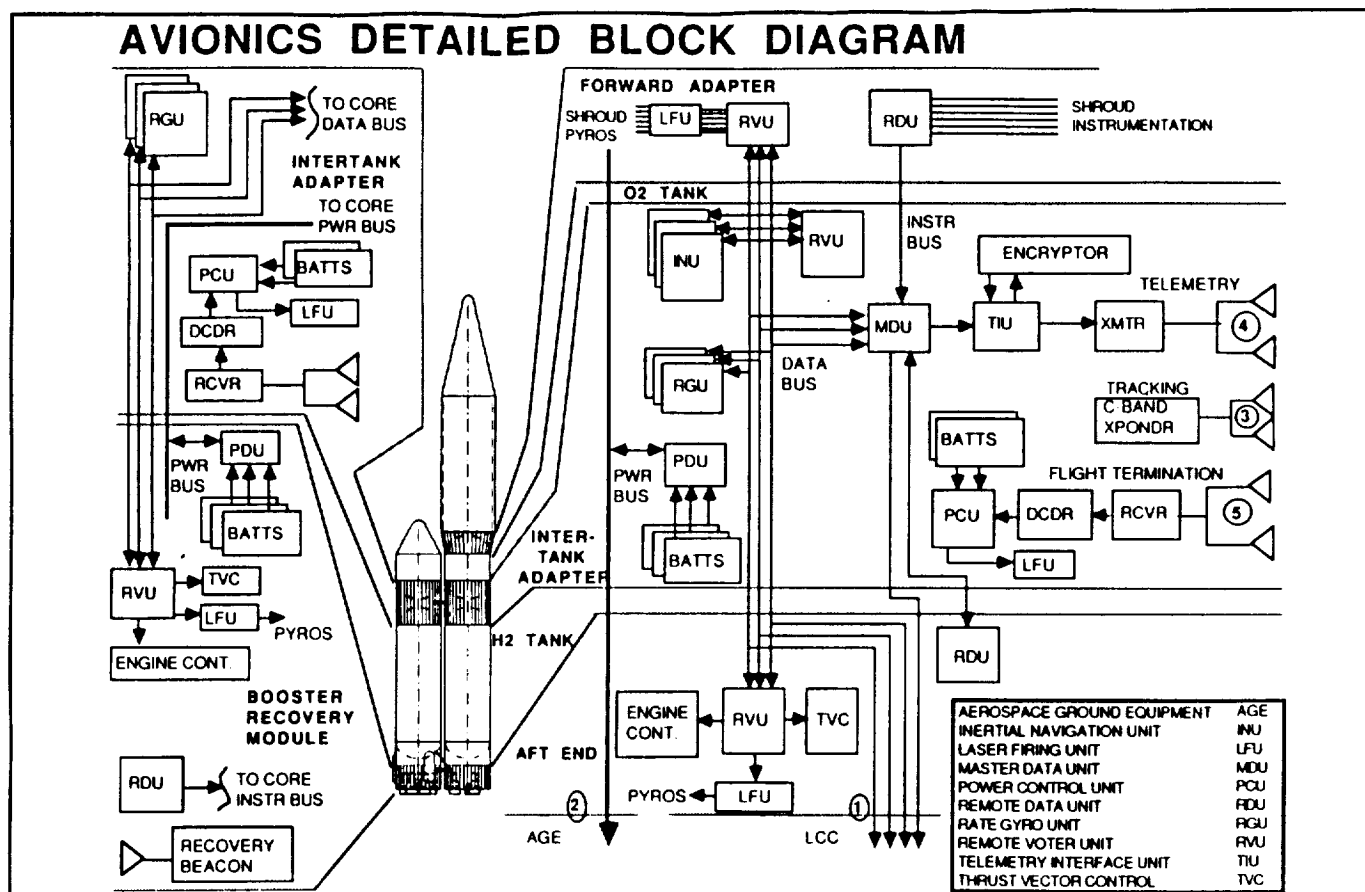


FIGURE 4.2.2-1 ALS AVIONICS &amp; POWER SYSTEMS

ALS CORE				
SUBSYSTEM (WITH HEALTH MONITORING)	WITH LIMITED EXPERT SYSTEMS			
	THRUPUT (MIPS)	TOTAL MEMORY (MBYTES)	I/O DATA RATE (MBPS)	I/O DEVICES (QUANTITY)
PROPULSION	3 (IMIPS/ENG)	0.288	0.375	819
FLUIDS	<0.1	<0.1	0.216	241
POWER	<0.1	<0.1	<0.01	100
# INSTRUMENTATION	<3	<0.002	0.256	1500
GN&C (ADAPTIVE)	4.063	0.988	0.153	600
SYSTEMS SOFTWARE	0.21	0.59	--	--
COMMUNICATIONS	<0.1	<0.1	<0.01	100
VEHICLE ELEMENT INTERFACE	<0.1	<0.1	0.072	262
TOTAL	10.47	2.06	1.09	3622
SHUTTLE COMPARISON	0.343	0.42	NA	~4000

# INCLUDES SENSOR PROCESSING NOT COVERED UNDER THE OTHER SUBSYSTEMS.  
NOTE: REDUNDANCY INCLUDED ONLY WHERE KNOWN (E.G., PROPULSION)

NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE ANY ALLOWANCE FOR MARGIN, OR FAILURE TOLERANCE. (EXCEPT FOR PROPULSION)

FIGURE 4.2.2-2 ALS CORE PROCESSING REQUIREMENTS

ALS LRB				
SUBSYSTEM (WITH HEALTH MONITORING)	WITH LIMITED EXPERT SYSTEMS			
	THRUPUT (MIPS)	TOTAL MEMORY (MBYTES)	I/O DATA RATE (MBPS)	I/O DEVICES (QUANTITY)
PROPULSION	7 (IMIPS/ENG)	0.672	0.875	1911
FLUIDS	--	--	0.216	241
POWER	--	--	<0.01	75
# INSTRUMENTATION	--	--	0.100	750
GN&C (ADAPTIVE)	--	--	0.153	300
SYSTEMS SOFTWARE	0.10	0.20	--	--
COMMUNICATIONS	--	--	--	--
VEHICLE ELEMENT INTERFACE	<0.1	<0.1	0.072	262
TOTAL	7.2	0.972	1.426	3539
SHUTTLE COMPARISON	0.343	0.42	NA	~4000

# INCLUDES SENSOR INTERFACING NOT COVERED UNDER THE OTHER SUBSYSTEMS.  
NOTE: REDUNDANCY INCLUDED ONLY WHERE KNOWN (E.G., PROPULSION)

NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE ANY ALLOWANCE FOR MARGIN, OR FAILURE TOLERANCE. (EXCEPT FOR PROPULSION)

FIGURE 4.2.2-3 ALS LRB PROCESSING REQUIREMENTS

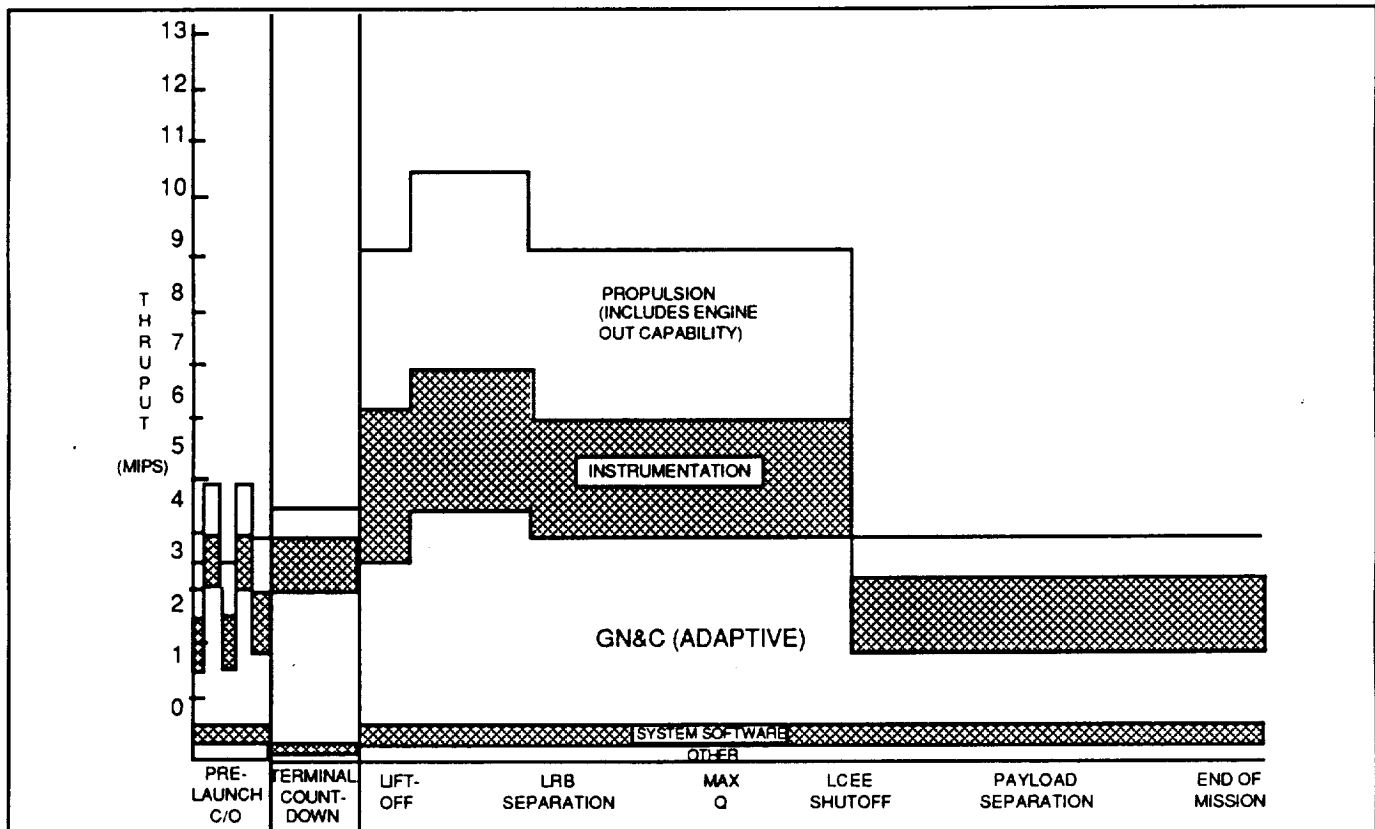


FIGURE 4.2.2-4 ALS THROUGH-PUT REQUIREMENTS



### 4.2.3 Target (FRWB, FRWB, PRCV)

The Phase 3 or Target configuration IOC has not been set, but if it is tied to the Fully Recoverable Wing Booster (FRWB), and the Partially Reusable Cargo Vehicle (PRCV) programs, it should be in 1996 to 1998.

Figure 4.2.3-1 outlines the Processing Requirements for the FRWB while Figure 4.2.3-2 associates the throughput requirements with the FRWB mission timeline. The FRWB avionics system is designed to be fully autonomous from launch to landing and roll out. The GBTs capability to support FRWB and PRCV development must start long before the 1996-1998 IOC. The GBT functions must include FRWB/PRCV related inputs in both Phase 1 and Phase 2. Typical of these inputs are:

- (1) Electromechanical Actuator applications in vehicle aero control and Thrust Vector Control systems;
- (2) Redundancy Management using Expert Systems and a distributed processing system; and
- (3) An autonomous, robust GN&C system capable of near all-weather launches and minimum tailoring of software mission to mission.

These technology driven requirements are discussed in the next section.

FULLY REUSABLE WINGED BOOSTER (FRWB)				
SUBSYSTEM (WITH HEALTH MONITORING)	WITH LIMITED EXPERT SYSTEMS			
	THRUPUT (MIPS)	TOTAL MEMORY (MBYTES)	I/O DATA RATE (MBPS)	I/O DEVICES (QUANTITY)
*PROPULSION	6 (IMIPS/ENG)	1.152	06	3264
FLUIDS	<0.1	<0.1	0.32	380
POWER	<0.1	<0.1	<0.01	180
# INSTRUMENTATION	<3	0.0048	0.320	4000
GN&C (ADAPTIVE)	5.199	1.264	0.394	1225
SYSTEMS SOFTWARE	0.24	0.79	--	--
COMMUNICATIONS	<0.1	<0.1	<0.01	120
VEHICLE ELEMENT INTERFACE	<0.1	<0.1	0.0256	5
TOTAL	14.64	3.42	1.67	9174
SHUTTLE COMPARISON	0.343	0.42	NA	~4000

\* PROCESSING IS TIME SHARED BETWEEN BOOSTER ENGINES AND AIR BREATHING ENGINES.

# INCLUDES SENSOR PROCESSING NOT COVERED UNDER OTHER SUBSYSTEMS.

NOTE: REDUNDANCY INCLUDED ONLY WHERE KNOWN (E.G., PROPULSION).

NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE ANY ALLOWANCE FOR MARGIN, OR FAILURE TOLERANCE (EXCEPT FOR PROPULSION).

NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE THE IMAGING SENSOR PECULIAR PROCESSING WHICH IS ASSUMED TO BE SELF CONTAINED.

FIGURE 4.2.3-1. FRWB PROCESSING REQUIREMENTS

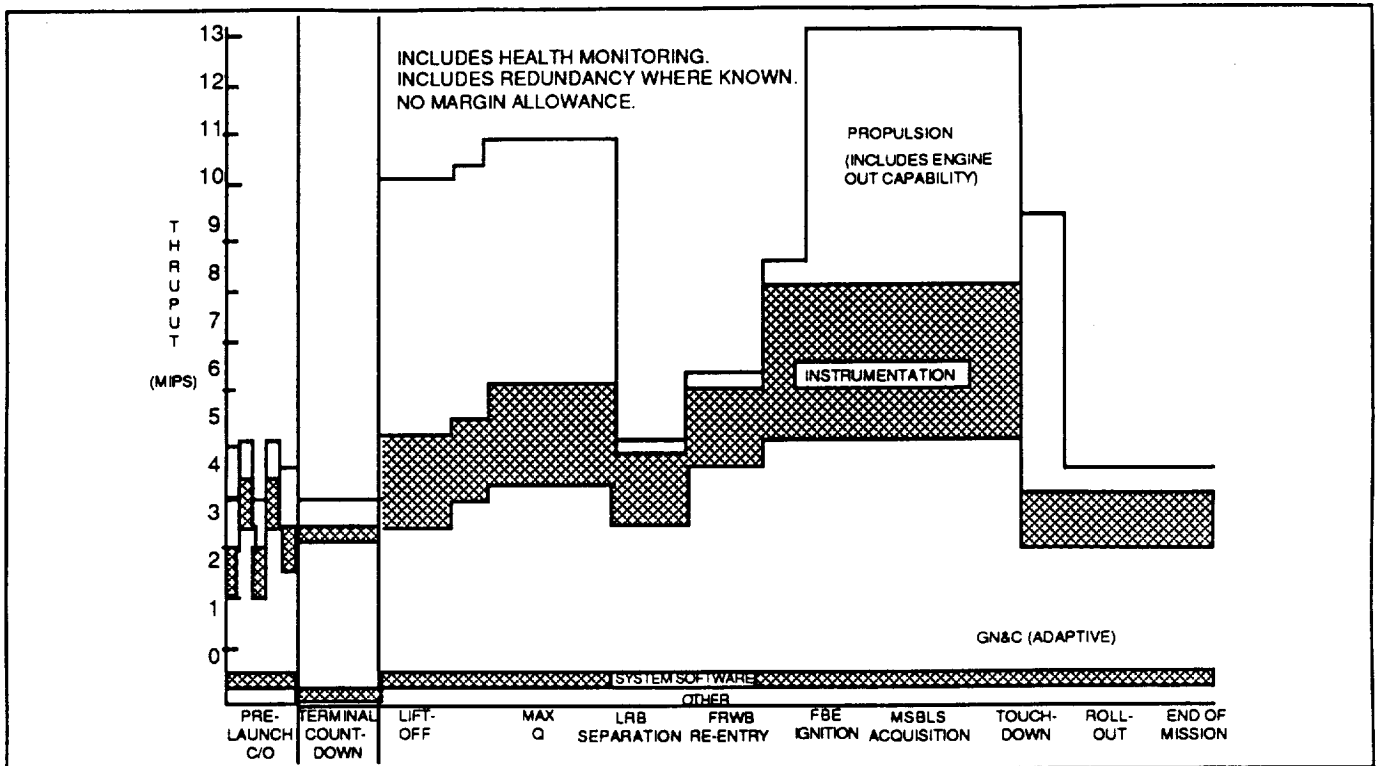


FIGURE 4.2.3-2. FRWB THROUGH-PUT REQUIREMENTS

### 4.3 Technology Driven Requirements

Several pacing technologies were investigated during the initial stages of this study. Each was associated with their specific application on the HLCV era avionics systems and prioritized as to their role in achieving the design goals. The following paragraphs show the impact on the GBT design.

#### 4.3.1 System Architectures/Redundancy Management

One of the most fundamental drivers of the GBT processing/throughput requirements involves the basic vehicle architectures to be simulated and the operational environment in which they must be tested. The basic Phase 1 through the complex Target GBT configuration had to be sized to full-up, end-to-end, real-time vehicle system simulations. This translates into a throughput requirement for the lab of about 150 million instructions per second (MIPS) for the Phase 2 GBT. The processor assigned to model the system architecture had to be able to model a parallel, distributed, multi-string system; duplicate the redundancy management logic of that system and be able to monitor, control and provide external stimuli to the system under test. The FRWB avionics system is fully autonomous and, therefore, includes Integrated Health Monitoring (IHM), and a high precision launch to launch GN&C system that may incorporate a multi-spectral Image Processing System. Much of the traditional GSE functions will be performed by the FRWB system. All these factors will drive the GBT throughput and parallel processing capacity well beyond the 150 MIPS of the Phase 2 lab. This mandates a main processing capacity which can be expanded incrementally without having to replace the original equipment.

### **4.3.2 Power Distribution, Conditioning and Management**

The HLCV era vehicles are required to perform over a wide ranging series of missions that last from 90 minutes to several months. The reliability required of the supporting power systems plus the new demands of cost effectiveness have driven a re-examination of traditional solutions and a search for new designs. The increasing demand for power by electromechanical actuators and the new designs being utilized in their attendant power supplies have elevated this once stable design area into new activity. The GBT power extension will be able to evaluate alternate power sources (batteries, fuel cells and solar cells), power distribution system architectures, redundancy management schemes, and different methods of power conditioning and management.

### **4.3.3 Electro Mechanical Actuators**

The clustered rocket engines of many of the HLCV vehicles have accelerated development of fast response high power (> 50 hp) electromechanical actuators. The HLCV GBT will support this effort in Phase 2. Development will be in the power supply design as well as that of the basic actuator.

The integration of actuator development and testing in the total vehicle development program involves several areas. The end-to-end testing would, in its highest fidelity mode, require the actuator under test to be dynamically loaded. This loading would be controlled in part by inputs from the missions environmental and vehicle dynamic models. The dynamic load cell and its attendant support equipment could represent a prohibitively high investment. Use of existing or dedicated actuator labs may prove the most cost effective method of providing this resource. A high data rate, broadband data link to the GBT could be used in closed loop testing. EMA power supply development could be accommodated in the GBT Power Systems extension.

### **4.3.4 Adaptive Guidance, Navigation & Control**

HLCV traffic models force a more robust launch capability. Not only do vehicles have to be easy to process and launch, they must be strong enough and smart enough to handle less favorable environmental conditions. Supporting Adaptive Guidance, Navigation & Control would include everything from concept evaluation through sensor design testing. Primary impact of this technology support by the GBT would be in the area of software development, and attendant processor capacity and flexibility. Special software analysis tools will be required in the investigation of various load relief concepts, sensor applications and vehicle dynamic control modeling.

### **4.3.5 Image Processing**

The application of image processing to HLCV functions seems particularly attractive in the areas of rendezvous & docking and approach & landing. The delays and subsequent risks involved in the remote docking techniques used in OMV can be potentially mitigated with a "smart" docking system. Such a system could be used on the STV or retrofitted on the OMV. Use of image processing to detect/identify the target, its range and orientation are well within current state-of-the-art capabilities. Application in the FRWB approach & landing functions is another application to be investigated.

Impact to the GBT design would include software tools required for high fidelity 3D Target modeling and animation. Hardware requirements would include prototype sensors, TV camera, large, high resolution graphic monitor and an image processing workstation.

#### **4.4 Reference Vehicle Avionics Equipment**

The Shuttle-C Option C Avionics system was used as the reference for the GBT Phase I design. This section provides a detailed description of this system.

##### **4.4.1 Shuttle-C Option C Hardware**

- The Shuttle-C, Option C avionics system uses existing Centaur based components
- Flight hardware and software delivered on a single pallet
  - Integrated Avionics Module (IAM) delivered with tested flight software and ground check-out software
  - Simple functional and contractual interfaces
- Duplicate Systems Integration Lab (SIL) and Software Development Lab (SDL) delivered to MSFC for independent IV&V
  - All tools have been proven on the Centaur program and are existing and in use today
- Ground hardware interfaces are unchanged, ground software changes will be limited to application packages.

##### **4.4.2 Shuttle-C Proposed Software**

- Flight Software
  - All flight software will be coded in Ada
  - Ada production tools are in place and in use at GD today for Centaur software production
  - Centaur Software Development Lab (SDL) provides for code development, generation, verification and validation
    - The SDL includes complete Flight Analogous Software Testing (FAST) capabilities
- Ground Software
  - Centaur modern avionics requires minimal changes to existing LPS software
    - Changes are only to the console checkout software
- All software will be developed and validated in the SDL and verified end-to-end using the avionics systems integration lab in a closed-loop, flight simulation environment.

##### **4.4.3 Shuttle C Avionics Components**

###### **4.4.3.1 Inertial Navigation Unit**

VENDOR: Honeywell

PRIME: General Dynamics

MASS: 55 lbs.

DIMENSIONS: 17.51" x 11.06" x 8.0" (L x W x H)

POWER: 28 V/DC Input/Max Consumption = 155 W Under Flight

**MAJOR COMPONENTS:** The INU shall consist of the following major subsystems:

- A. Inertial Measurement System: Three axis strapdown system containing accelerometers and ring B laser gyros plus electronics (processor\*, memory, I/O, etc.) to perform inertial measurements compensation, alignment, attitude integration, and filtering.
- B. Flight Control Subsystem: 1750 processor, memory, memory management and I/O provisions necessary for vehicle and ground systems interfaces.

**INTERFACE DEFINITION:**

- MIL-STD-1553 Serial Control Data I/O (3).
- Inertial Processor to Flight Control Processor Internal Communication is DMA.
- Flight Control to Inertial Processor is 1553.
- Other unique I/O can be accommodated.
- Cross strap ports for redundant configuration.

**PERFORMANCE: (IMS)**

- Modes: Simulation IMS Test "A" & "B", alignment, inertial, BIT.
- Autonomous AZ align accuracy within 270 Arcsec (3- Sigma) in 45 minutes.
- Autonomous level align accuracy within 30 Arcsec (3- Sigma) in 45 minutes.

Parameter	Laser Gyro (Compensated, Max 3 sigma)	GDSS Specification (3 sigma)	Units
Random Walk	0.0035	0.006	deg/rt hr
Bias Stability	0.006	0.01	deg/hr
SF Uncertainty	10.0	15.0	PPM
SF Asymmetry	4.0	5.0	PPM
(3 deg/sec)			
LA Stability	10.0	15.0	arc-sec

**PERFORMANCE: (FCS)**

- CPU shall be CMOS/SOS
- Bit error rate due to Single Event Upsets less than 10<sup>-7</sup>/hr at geosync altitude.
- MIL-STD-1750 Instruction Set throughput shall be a minimum of 1 MIPs.
- Memory shall have a minimum addressing capability of 256K words.

**ENVIRONMENTAL COMPATIBILITY  
OPERATIONAL**

- MIL-STD-1540
- Temperature: Qualified
- Humidity: -11 to +140°F
- Pressure: 0 to 100%
- Acceleration: 0.1 psig
- Galactic Cosmic: 10 g
- Galactic Cosmic: <10<sup>-7</sup>/hr SEU and no latch-up.

**RELIABILITY:**

- MTBF: 75,000 Hours

## COMPATIBILITY WITH OTHER SYSTEMS:

- Titan/Centaur
- Atlas/Centaur
- Shuttle C
- ALS
- ASPS

## AVAILABILITY:

- (TC-12) First flight unit delivery 02-15-90/First flight on A/C 4/1/91

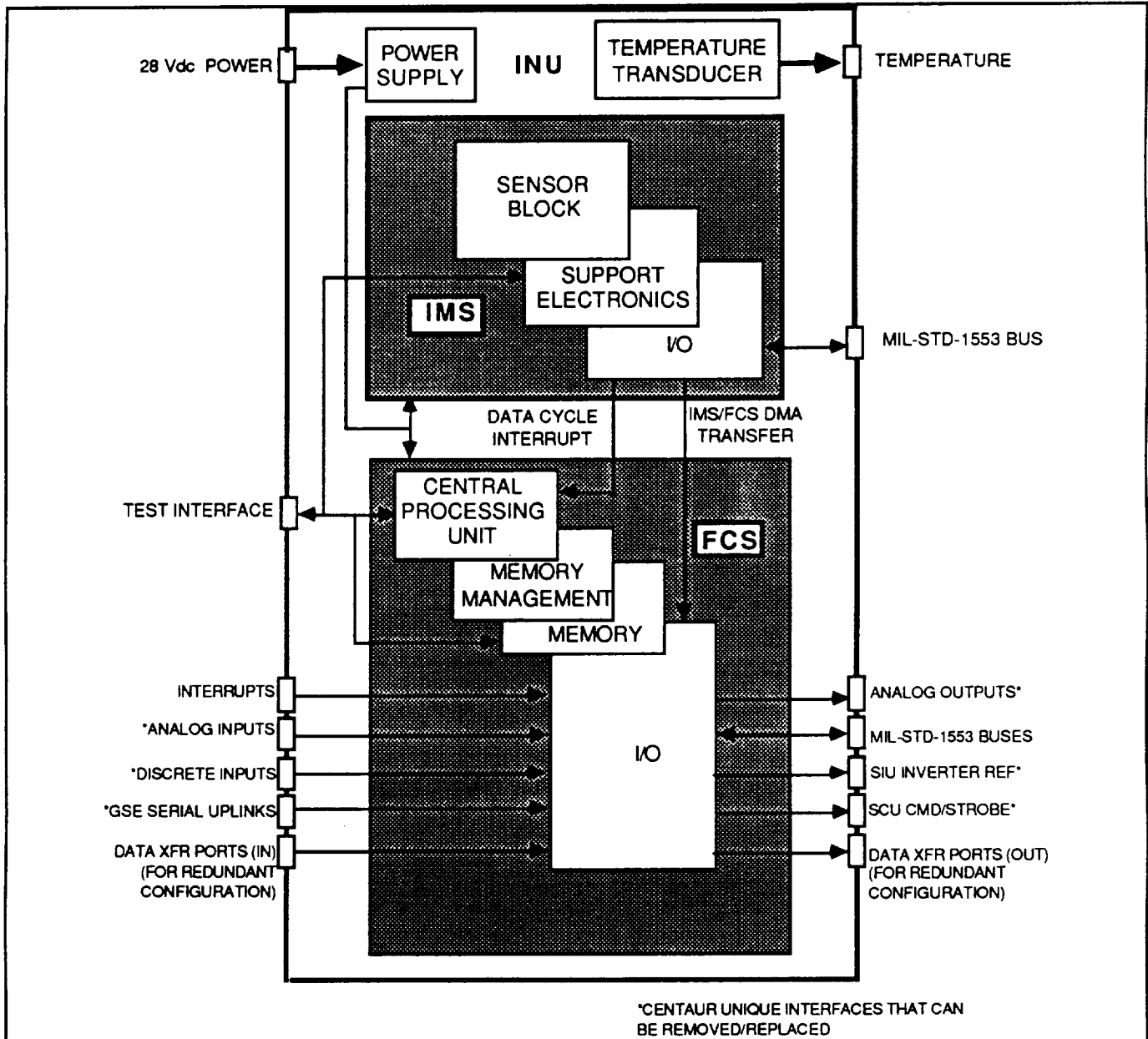
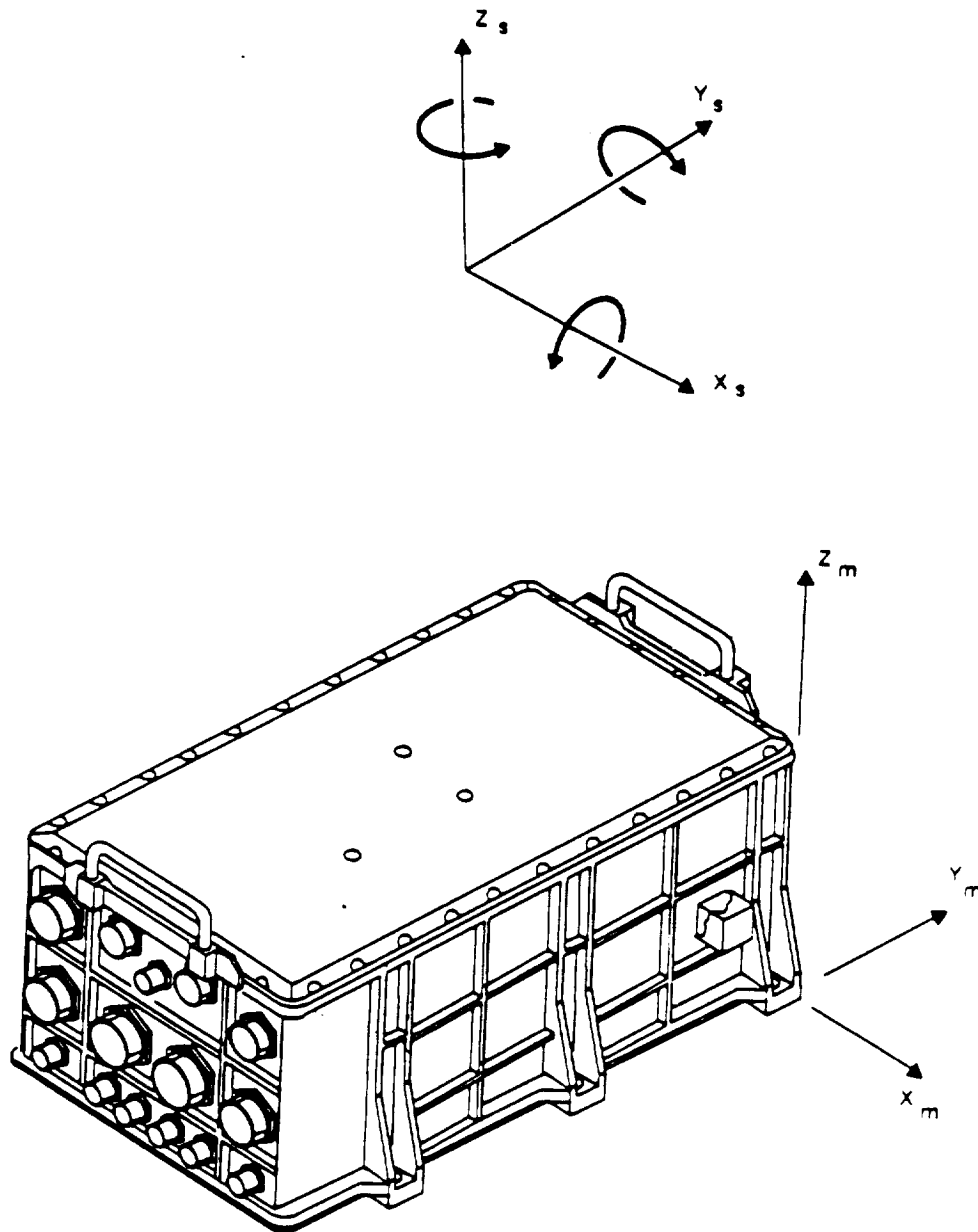


FIGURE 4.4.3.1-1. INU FUNCTIONAL INTERFACES



Note: The sensor reference axes  $(X_s, Y_s, Z_s)$  shall be nominally aligned to the item mounting axes  $(X_m, Y_m, Z_m)$  to within the accuracy specified in Table IV.

FIGURE 4.4.3.1-2. INERTIAL REFERENCE UNIT PACKAGING OUTLINE

#### 4.4.3.2 Data Aquisition System (DAS)

VENDOR:

MASS: MDU 10 lbs  
RDU 10 lbs

PRIME:

DIMENSIONS:

POWER:

##### 4.4.3.2.1 Data Aquisition System Functions

- A. The Shuttle C telemetry system monitors the safety and performance of all vehicle subsystems. A wide variety of signal types are received and processed including acceleration, vibration, temperatures, pressures, currents and voltages, tachometer signals and discretes.
- B. The heart of the telemetry system is the data acquisition system (DAS), made up of a master data unit (MDU) and two remote data units (RDU's). The DAS provides the capability to monitor several hundred unique vehicle parameters in addition to guidance and navigation and spacecraft data prior to launch and throughout all phases of flight.
- C. The DAS, which will be developed and qualified for first use with the commercial Atlas/Centaur program, has a high potential for implementation on all launch vehicles produced by General Dynamics Space Systems Division. The system design provides increased flexibility and performance at reduced cost and weight.
- D. The MDU provides transducer excitation, signal conditioning and encoding for all front end measurements in addition to receiving and formatting data from the spacecraft, the digital computer unit (DCU) and two RDU's. The MDU provides two PCM outputs, one of which is connected to the transmitter, the other is used to provide a hardline link to the telemetry ground station.
- E. The two RDU's provide excitation, signal conditioning and encoding for all end measurements. The RDU's output this data, upon command, to the MDU.

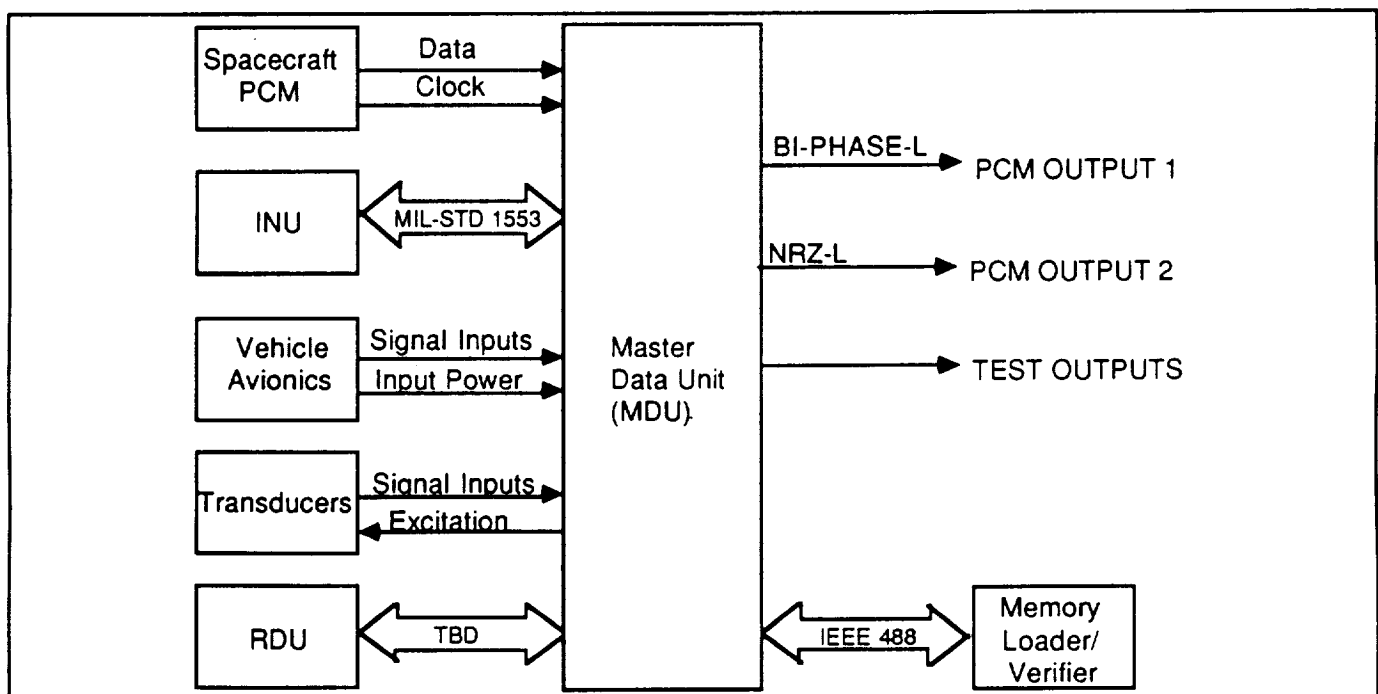


FIGURE 4.4.3.2-1. DAS



**INTERFACE DEFINITION (MDU):****Digital Interfaces:****Remote Data Unit (RDU)**

Quantity of RDU's

Operating distance

Bus Type

up to 6, jettisonable

up to 200 ft from MDU

vendor specified

**Spacecraft PCM Input**

Input bit rate

Signal type

up to 4 KBPS, asynchronous

NRZL

**MIL-STD-1553**

Interface type

No. of messages

Message length

RT, transformer coupled

programmable (TBD max)

programmable (TBD max)

**INTERFACE DEFINITION (RDU):****Digital Interfaces:****Master Data Unit (MDU)**

Operating distance

Bus type

up to 200 ft from MDU

vendor specified

**PERFORMANCE (MDU)****High level analog**

Spans

Offsets

Filtering

Cutoff frequency

Sample rates

8 software selectable

250 bipolar, software programmable

digital, low pass, FIR type

8 software selectable

format programmable

**Low level analog**

Spans

Offsets

Filtering

Cutoff frequency

Sample rates

8 software selectable

250 software programmable

digital, low pass, FIR type

8 software selectable

format programmable

**Resistance**

Current sources

Spans

Offsets (course)

(fine)

Filtering

Sample rates

2, mirrored, multiplexed

8 software selectable

2, software selectable

250 software programmable

digital, low pass, FIR type

format programmable

**Pulsed input**

Frequency range

Sample rates

Counter

Vin

determined by sample rate

format programmable

8 bit, reset after reading.

0.5 to 25 V p-p

**Bi-Level**

Logic 1	+3 to +35 VDC
Logic 0	-10 to +1 VDC
inputs/data wd	8
Attenuators	
Ratio	10:1
vin (max)	50 VDC
Excitation	
High level transducers	28 VDC, 30 mA nominal foldback protected @ 100 mA
Discretes	28 VDC, 3 mA max
Strain gauge transducers	10 VDC
Potentiometric transducers	5 VDC
PCM Outputs	
PCM Output 1	filtered NRZL
PCM Output 2	MRZL, BNC connector
Bit Rates	
No of bit rates	4, command selectable
Bit rates	16K, 32K, 64K, 128K BPS
Bit rate tolerance	01%
PCM Formats	
No. of formats	4, command selectable
Major frame length	1 to 256 minor frames, software programmable
Minor frame length	16 to 1024 words, software programmable
Word length	8 bits
Bit order	MSB first
Programmability	
Memory type	EEPROM
Interface	IEEE-488
Language	TBD
PERFORMANCE (RDU)	
High level analog,	
Spans	8 software selectable
Offsets	250, bipolar, software programmable
Filtering	digital, low pass, FIR type
Cutoff frequency	8, software selectable
Sample rates	format programmable
Low level analog	
Spans	8, software selectable
Offsets	250, software programmable
Filtering	digital, low pass, FIR type
Cutoff frequency	8, software selectable
Sample rates	format programmable

Resistance	
Current sources	2, mirrored, multiplexed
Spans	8, software selectable
Offsets (course)	2, software selectable
(fine)	250 software programmable
Sample rates	format programmable
Pulsed input	
Frequency range	determined by sample rate
Sample rates	format programmable
Counter	8 bit, reset after reading.
Vin	0.5 to 25 V p-p
Bi-Level	
Logic 1	+3 to +35 VDC
Logic 0	-10 to +1 VDC
Inputs/data wd	8
Attenuators	
Ratio	10:1
Vin (max)	50 VDC
Excitation	
High level transducers	28 VDC, 30 mA nominal foldback protected @ 100 mA
Discretes	28 VDC, 3 mA max
Strain gauge transducers	10 VDC
Potentiometric transducers	5 VDC
Programmability	
Memory type	EEPROM
Interface	IEEE-488
Language	TBD

## ENVIRONMENTAL COMPATIBILITY:

## PHYSICAL CHARACTERISTICS (MDU)

Environments (IAT)	
Temperature	-40 to +70°C radiative cooling only
Acceleration	±10 g
Shock	TBD
Vibration	TBD
Humidity	±100%

## PHYSICAL CHARACTERISTICS (RDU)

Environments (IAT)	
Temperature	-40 to +70°C radiative cooling only
Acceleration	±10 g
Shock	TBD
Vibration	TBD
Humidity	±100%

#### 4.4.3.2.2 Remote Voter Unit (RVU)

PRIME: General Dynamics/Space Systems Division  
MASS: 35 lb. DIMENSIONS: 12.00" x 8.25" x 8" (L x W x H)  
POWER: 28 VDC Input, MAX POWER  
CONSUMPTION: 35 watts/max (80 switches ON)

MAJOR COMPONENTS: The RVU shall consist of the following major functions:

- A. MIL-STD-1553B Bus Interface: Three independent Remote Terminal Interface Units, each powered by its own power supply, shall control 1553B data flow and associated protocol.
- B. Control Logic: Performs majority voting of vehicle load switching information, as well as engine position information, multiplexes digital instrumentation data and performs built-in-test.
- C. Solid State Switches: 80 solid state switches provide +28VDC power to vehicle sequencing and safety functions, including pyrotechnic loads. Redundant +28VDC buses and series/parallel switch configurations shall provide single failure tolerant controls.

#### INTERFACE DEFINITION:

- Receives vehicle sequencing commands from the INU across three MIL-STD-1553 avionic buses.
- Transmits switch status and built-in-test data over all three MIL-STD-1553B avionic buses in response to IMU commands. (This data may be directed back to the INU or to the Master Data Unit (MDU)).
- Provides thrust vector control output to hydraulic servovalves (on Centaur).
- Capable of 80 (40 prime and 40 backup) switched +28VDC discrete outputs to pyrotechnic and other vehicle sequencing loads.
- Independent +28VDC power inputs (prime and backup).

#### PERFORMANCE:

- Modular construction: communications card, controller card, solid state switch cards, and TVC card.
- Adaptable to single bus configuration.
- Provides 80 dedicated solid state switch closures for up to five 16-bit switching words.
- Throughput (from receipt of a single switching command to switched +28VDC unloaded output over temperature discounting bus skew): 3 MSEC max.
- Instrumentation word resolution : 8 bits.
- TVC word resolution: 10 bits.
- Memory shall have a minimum addressing capability of 16K 16-bit words.

#### ENVIRONMENTAL COMPATIBILITY:

- Meets both Atlas/Centaur and Titan/Centaur temperature, acceleration, shock, vibration and humidity environments.

#### RELIABILITY:

- Incorporates MIL-M-38510 Class S electronics parts or, when necessary, screened Class B parts.
- CMOS-epitaxial parts with frequent updating help prevent and correct for single event upset.

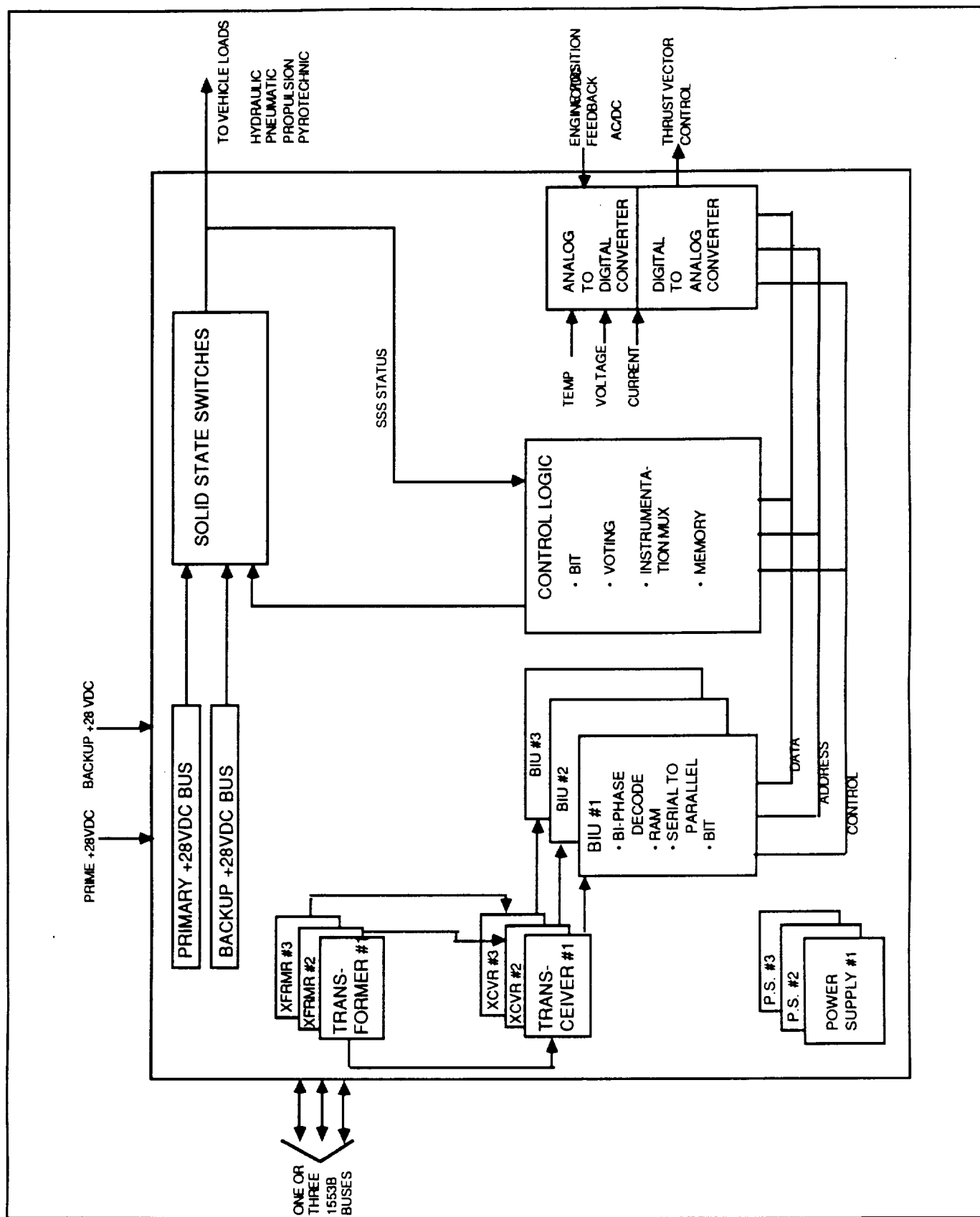


FIGURE 4.4.3.2.2-1. REMOTE VOTER UNIT (RVU)

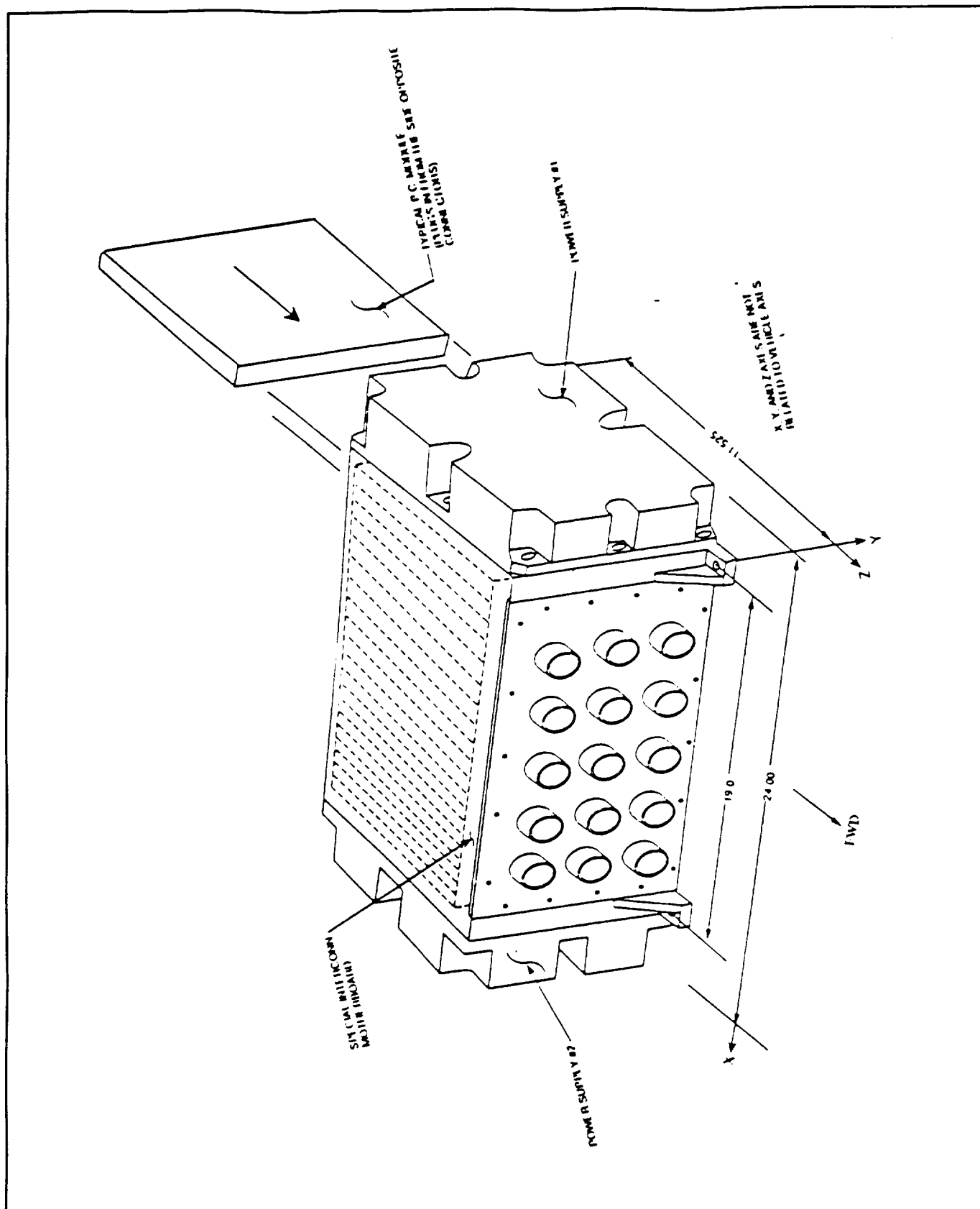


FIGURE 4.4.3.2.2-2 RVU MODULAR DESIGN

#### 4.4.3.2.3 Electrical Distribution Unit (EDU)

PRIME: General Dynamics/Space Systems Division  
MASS: 62 lb. DIMENSIONS:  
POWER: SEE ATTACHED BREAKDOWN

##### TOP LEVEL COMPONENT DESCRIPTION:

- The EDU is a single piece of electrical equipment containing relays, contractors, fuses, diodes, voltage monitors, and current shunts. The EDU provides the only electrical power interface between Centaur, Payload and the Orbiter vehicle, with the exception of the Payload Centaur Aerospace Ground Equipment Power.

##### DC SYSTEM DESCRIPTION COMMON TO G PRIME

- Orbiter power input shall provide the capability to handle the following steady state power:
  - CISS Main Bus: Component Rating, 150 Amps at 28V DC (4.2 KW)
  - Payload Bus: Component Rating, 1800 Watt out CRU Input, 80 Amps at 25V DC (2000W)
  - CISS Main Bus: Thermal Capacity, 120 Amps at 28V DC (3.36 KW)
  - Payload Bus: Thermal Capacity, 1500 Watt out CRU, Input (1666.7W) 66.7A at 25V DC.
- Maximum voltage drop from orbiter power interface to the CISS DC main bus and the payload power bus is .95V DC.
- Application of power to the CISS DC main bus is through a 200 amp contactor.
- Application of power to the payload power bus is through a 100 amp contactor.
- Orbiter provides four (4) Aught gauge positive wires and four (4) Aught gauge return wires.
- Each positive line shall be fused with an 80 amp fuse to protect the vehicle wiring.
- Each twenty (20) cell input shall be rated for 150 amps at 28 Volts (4.2 KW).
- Application of power is through a 200 amp contactor.
- Maximum voltage drop from the battery twenty (20) cell tap to the CISS DC main power bus is .95V DC.
- Two (2) 4 gauge positive wires and two (2) 4 gauge return wires for each battery twenty (20) cell tap input.
- Battery 1 and 2 inputs shall be in separate connectors.
- The seventeen (17) cell input provides the following power capability:
  - A. 150 Amps at 28V DC (4.2 KW) to the CISS DC main power bus for approximately 260 MX.
  - B. 2.00 KW (95.3 amps at 21V DC) to the payload power bus for approximately 260 MSEC.
- The seventeen (17) cell input floats on the CISS DC main bus and the payload power bus and provides a floor voltage to these buses during an orbiter failure.
- Application of power to the CISS DC main bus is through a 200 amp contactor.
- Battery 1 and 2 inputs shall be routed in separate connectors.
- Maximum voltage drop from the battery seventeen (17) cell tap to the CISS DC main bus is .95V DC.

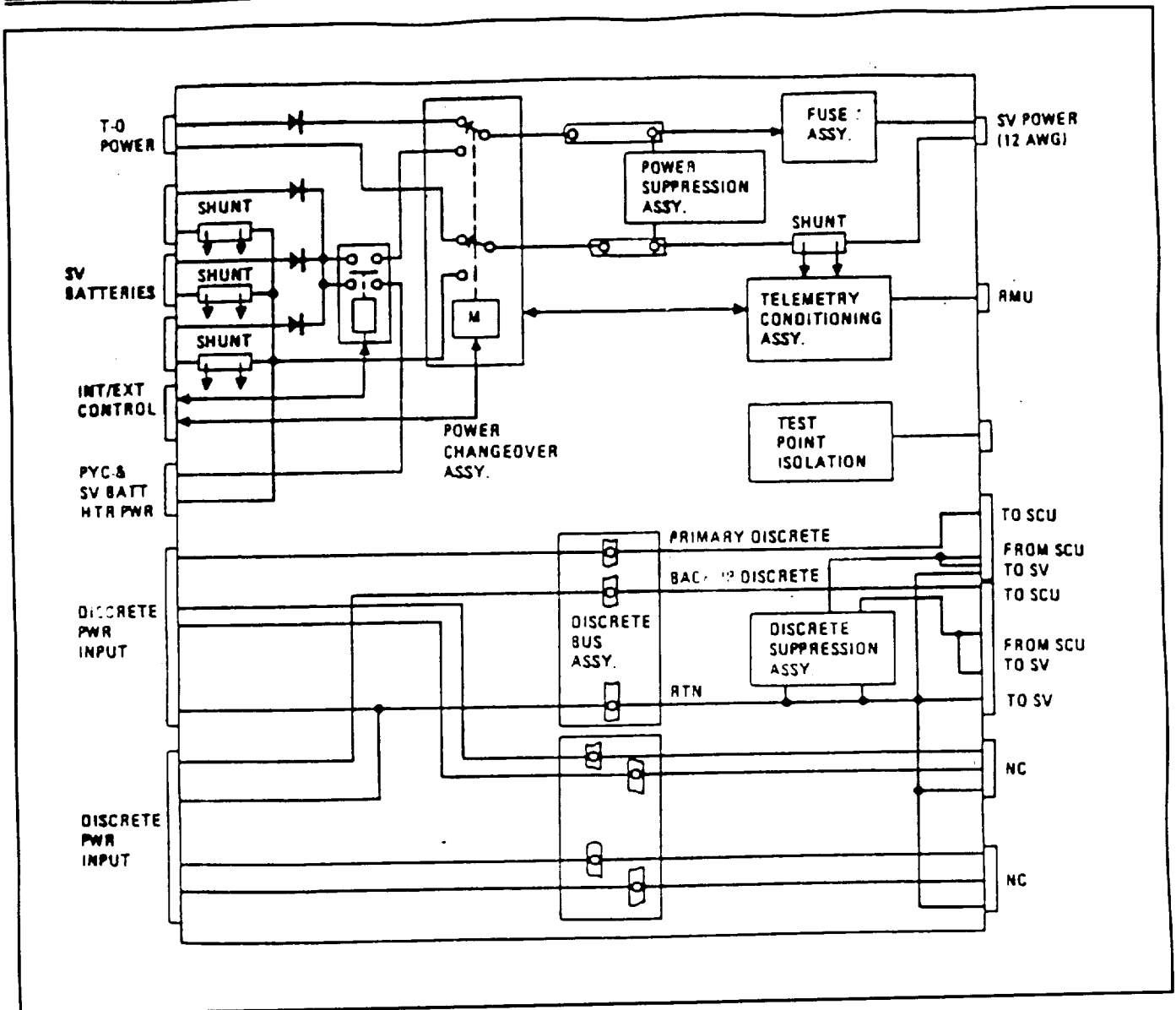


FIGURE 4.4.3.2.3-1. DETAIL BLOCK DIAGRAM - DC POWER DISTRIBUTION AND CONTROL

#### AC SYSTEM DESCRIPTION COMMON TO G PRIME

- Two failure tolerance required
- Provides reversal of phases A and B.
- AC inputs are to be fuse protected.
- Provide TLM to determine position of phase reversal relay and the amplitude of the AC phase voltage.
- Each source is 400 Hz 115/200VAC RMS
- Motor load circuit rating, 10 = .5 AMPS Maximum.

#### CENTAUR G EDU THERMAL ANALYSIS STATUS

- Worst case hot: evaluation of EDU thermal control is through detailed thermal analysis.



- Thermal Environments:  
On-Orbit abort mission  
In-bay ZLV orbit
- Maximum power dissipation used in detailed analysis to date is 172 watts, based on off-design condition of a 1500W CRU output with a 90 percent CRU efficiency.
- Worst case cold: EDU thermal control maintained by internal power dissipation of 50 watts (minimum).

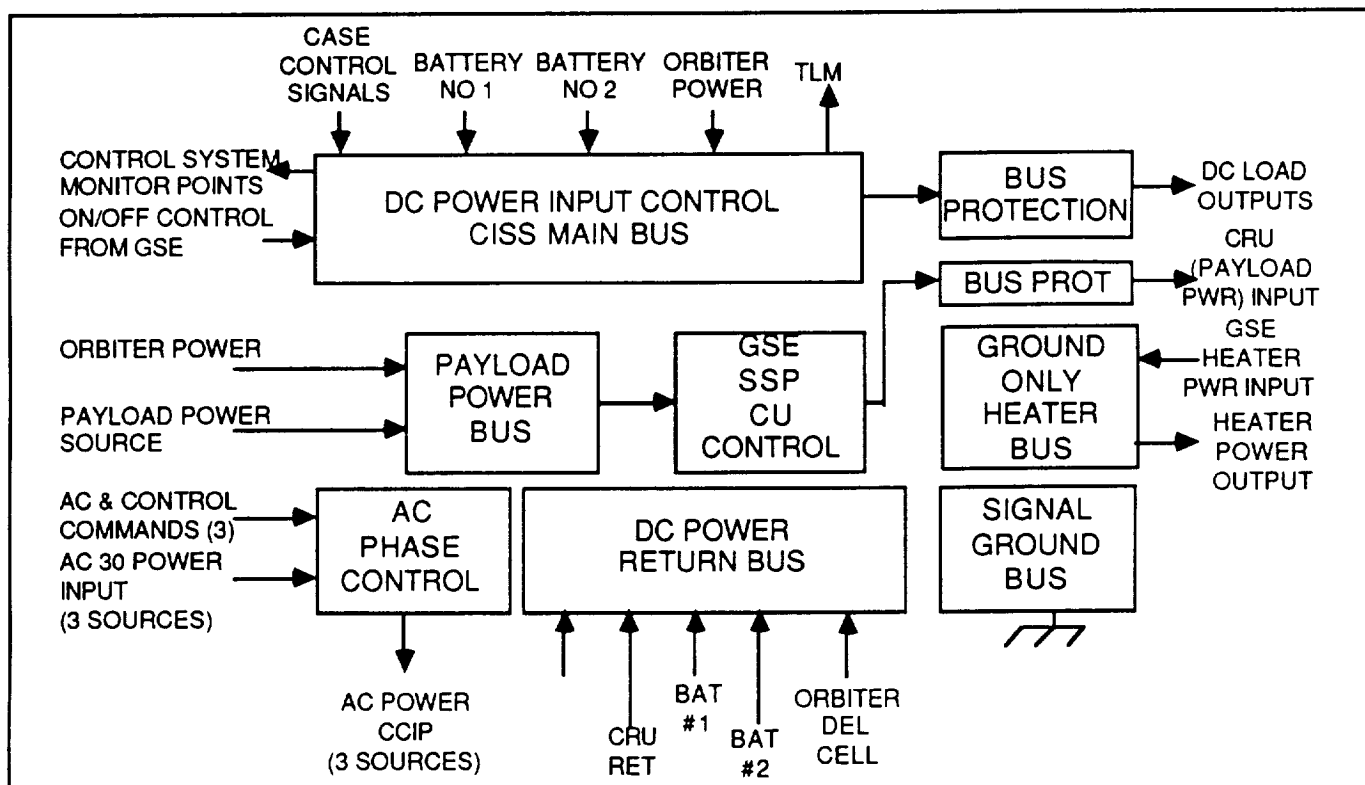


FIGURE 4.4.3.2.3-2. EDU FUNCTIONAL BLOCK DIAGRAM

#### 4.4.3.2.4 Silver Zinc Battery

VENDOR:

MASS: 194 lb.

DIMENSIONS:

PERFORMANCE:

**Low Voltage Tap.** The output voltage shall not be less than 23.63 volts and not more than 27.45 volts and capable of delivering steady state current of 120 amperes for 300 milliseconds while at specified temperature range during any point of battery rated discharge. The item shall reach the output voltage within 10 milliseconds after application of the 120 ampere load.

**Full Voltage Tap.** The output voltage shall be between 27.0 and 32 volts and capable of delivering steady state currents of 80 to 120 amperes while at specified temperature range

during any point of battery rated discharge. The item shall reach the output voltage within 10 milliseconds after application of any load between 80 and 120 amperes.

Capacity. 650 ampere-hours, minimum for -1; 375 ampere-hours for -2.

Open Circuit Voltage. The open circuit voltage shall not be more than 32.3 Vdc for the full cell tap and 27.45 Vdc for the low cell tap 24 hours after initial activation.

## ENVIRONMENTAL

Environmental Conditions. The item shall be capable of withstanding any probable combination of the environmental conditions specified herein with no detrimental effects.

### Temperature

Operating. The item shall be capable of satisfactory operation under temperature conditions as follows:

- a. The item shall be capable of standing in the activated condition while in a daily radiant temperature cycle with a lower limit of 45°F for 14 hours and an upper limit of 90°F for 10 hours for a period of 30 days.
- b. The item shall be capable of discharge - while in a radiant temperature between 20°F and 120°F for a period of 6.5 hours, with heater power available and with loads as specified in Performance section above.
- c. The item shall be capable of standing the activated condition or discharging while radiating to a deep space environment while mounted to a base maintained at 0°F, with heater power available and load as specified in Performance section above.

### Non-Operating

Unactivated. The item shall be capable of safe storage and transportation without impairment of its capabilities from the effects of temperature under the following conditions:

- a. Lower Limit - minus 65°F for periods of at least 8 hours duration.
- b. Upper Limit - plus 125°F plus the full impact of solar radiation, 360 BTU per square foot per hour, for periods of 4 hours per day; or plus 160°F with no solar radiation for periods of 4 hours per day, not to exceed 30 days.
- c. Temperature shock resulting from rapid temperature changes within the above limits.
- d. Continuous storage, in the unactivated condition, in temperatures between plus 30°F and plus 45°F for a period of 5 years.

Activated. The item shall be capable of safe storage without impairment of its capabilities from the effects of a storage temperature of 35°F ± 10°F for 30 days.

### Atmospheric Pressure.

Operating. The item shall be capable of operating within a cycling pressure range of 760 mm of mercury to  $1.5 \times 10^{-10}$  mm of mercury.

Non-Operating. The item shall be capable of withstanding pressure ranging from between 760 mm of mercury and 87 mm of mercury (equivalent of sea level to 50,000 feet) in storage and transportation.

Humidity. The item shall be capable of operating and storage at relative humidities of up to 100 percent including condensation due to temperature change.

#### Atmospheric Elements.

Operating. The item shall be capable of operating in its installed location in any probable combination of the following atmospheric elements: rain, fog, smoke, wind, ozone, sand and dust, sunshine, and salt atmosphere.

Explosive atmosphere. The item's heater shall operate in an explosive atmosphere without causing ignition of that atmosphere.

Non-Operating. The item shall be capable of storage and transportation without impairing its capabilities from effects of any of the probable combinations of the following atmospheric elements: rain, snow, sleet, hail, ice, fog, smoke, wind, ozone, sunshine, sand and dust, and salt atmosphere.

#### **4.4.3.2.5 Lithium Thionyl Chloride Battery**

VENDOR:

MASS: 68 lb.

DIMENSIONS:

#### **PERFORMANCE:**

Output Power. The output voltage shall remain between 26 and 32 volts with the battery delivering steady state currents of 14 to 60 amperes and pulse currents of 75 amperes for not more than two minutes each, at least, twice during the discharge period while at specified temperature range during any point of battery rated discharge. The Seller shall inform the Buyer of all penalties, if any, resulting from the foregoing range requirements. The item shall reach the output voltage within 10 milliseconds maximum after application of any load between 14 and 60 amperes. In case of 10 milliseconds maximum criterion is not met, the Seller shall provide the Buyer with the minimum time required to reach the output voltage and any battery preconditioning procedure and the associated penalties. The procedure shall be reviewed and approved by the Seller. The item shall be capable of specified performance when operated in any combination of one(1) to three (3) batteries providing power when connected in parallel.

Capacity. 250 ampere-hours minimum.

Open Circuit Voltage. The open circuit voltage of the item shall not be less than 32.4 Vdc.

Heater. The heater, if required, shall be designed to bring the item temperature to its minimum operating temperature from a minimum stabilizing temperature of plus 40F within 10 hours. The heater shall maintain acceptable thermal control. As a design goal, the heater power shall be minimized and be rated at 28 Vdc. The heater shall be designed such

that a continuous power application, for a period of up to 90 days, will not provide a temperature high enough to damage the battery and/or cells. The resistance of the heater circuit shall be provided by the Seller.

**ENVIRONMENTAL.** The item shall be capable of withstanding any probable combination of the environmental conditions specified herein with no detrimental effects.

#### Temperature.

Operating. The item shall be capable of satisfactory operation under any combination of the environments below:

- a. The item shall be capable of standing in the activated condition for a period of 90 days while in a conductive, convective and radiative environment ranging from 45 to 90 degrees F.
- b. Worst Case Cold, Pre-Launch. The item shall be capable of discharge in accordance with Performance (above) after reaching thermal equilibrium in a 40 degree F radiative and convective environment.

**NOTE:** Convective and radiative, heat transfer shall be assumed to occur over all item surfaces. The average convective heat transfer coefficient will be 4 BTU/Hr ft<sup>2</sup>.

#### Atmospheric Pressure.

Operating. The item shall be capable of operating within a cycling pressure range of 760 mm of mercury to  $1.5 \times 10^{-10}$  mm Hg. (The time duration for this change shall be a minimum of 5 minutes.)

## **5.0 GBT IMPLEMENTATION PLANNING**

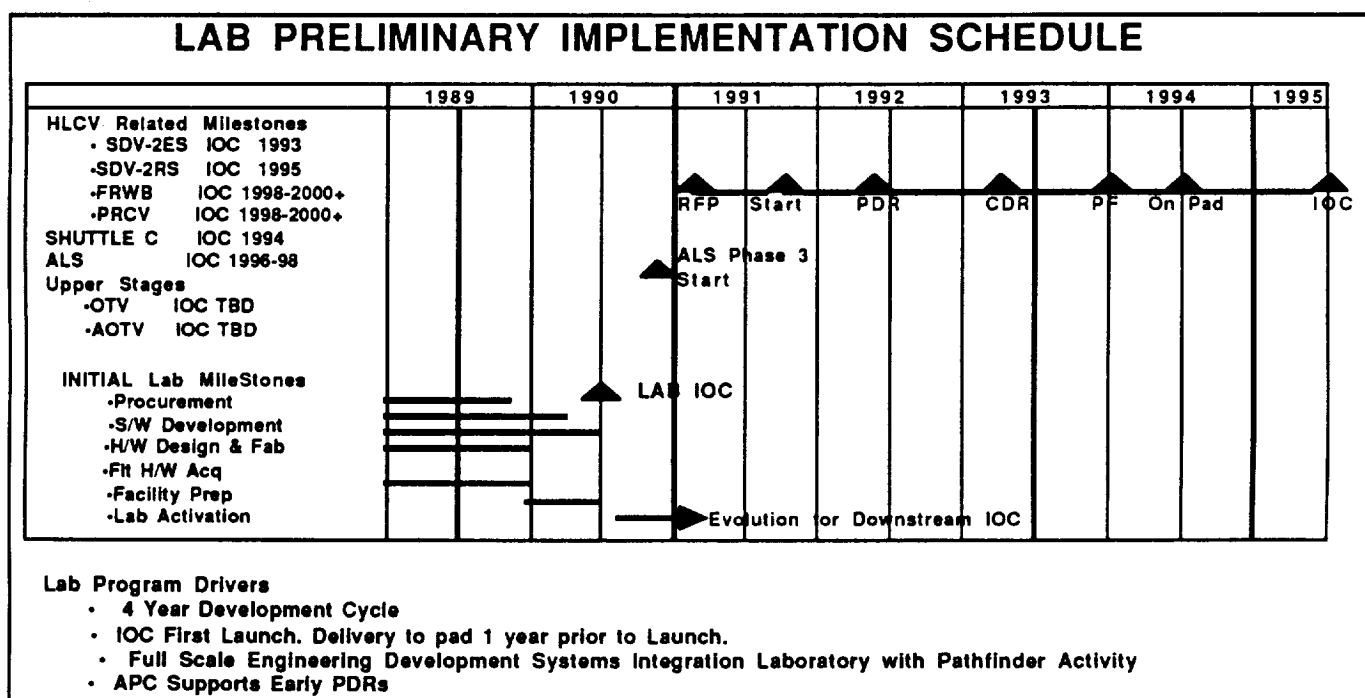
From the beginning, it was recognized that the Ground Based Test beds capabilities would be tied to meeting current program system testing requirements. The GBT's role was to encompass vehicle simulation and testing needs from inception to the Preliminary Design Review (PDR). Looking at the projected vehicle developmental schedules, it was all too clear that the first operational GBT capabilities would have to be focused on the critical developmental problems. If vehicles like the Shuttle C or STV were to be supported prior to their PDR's the GBT must be at least operational by August 1990. Basic avionic system architectural issues would have to be addressed first. The initial GBT would have to provide high fidelity, precision guidance & navigation simulations that supported evaluation of the several configurations being investigated. This dictated identification of long lead items like the 3-axis table.

Software model development is another key factor in the implementation plan. Fidelity of the vehicle dynamic and system models is critical to establishing the GBT as a valuable program development resource. This usually requires actual hardware being used to develop and verify the fidelity of the respective software models. Availability of similar hardware often proves to be another pacing element.

Accelerating the application of new, useful technologies into current and future programs was another stated goal of the GBT. To this point, all the GBT capabilities were directed at specific problems of specific programs because of time related and money related constraints. The implementation plan has evolved to the point that permits visibility as to how this goal can be realized. First, the basic GBT hardware and software design is modular and thus can be changed easily to accommodate different requirements. The early phases of implementation require the building of a specific number of these basic modules to satisfy a limited number of needs. To satisfy a greater set of requirements relatively few new modules are required.

Figure 5.0-1 shows an early implementation schedule and its assumptions. One of the most difficult problems of the implementation schedule, shown earlier in figure 1.2-2, is the amount of work to be done in the first phase. Between February 1989 and August 1990, over 60% of the total task must be accomplished. This is not consistent with the relatively low front end funding guidelines that were provided for this study. Figure 5.0-2 shows this problem graphically.

The bottom line for GBT success is being able to supply the most cost effective and useful test facility at the time when new programs need it the most. This implies that the projects are willing to pay their way and plan for such usage initially. This idealistic form of funding must be recognized as supplemental to basic level of funding needed to initially implement and later maintain GBT operations. Internal Research & Development projects are also a source of funding. This type of function typically accelerates the application of useful, new technologies and test concepts upon which later major programs are built.



**FIGURE 5.0-1. IMPLEMENTATION PLAN**

## IMPLEMENTATION ISSUES

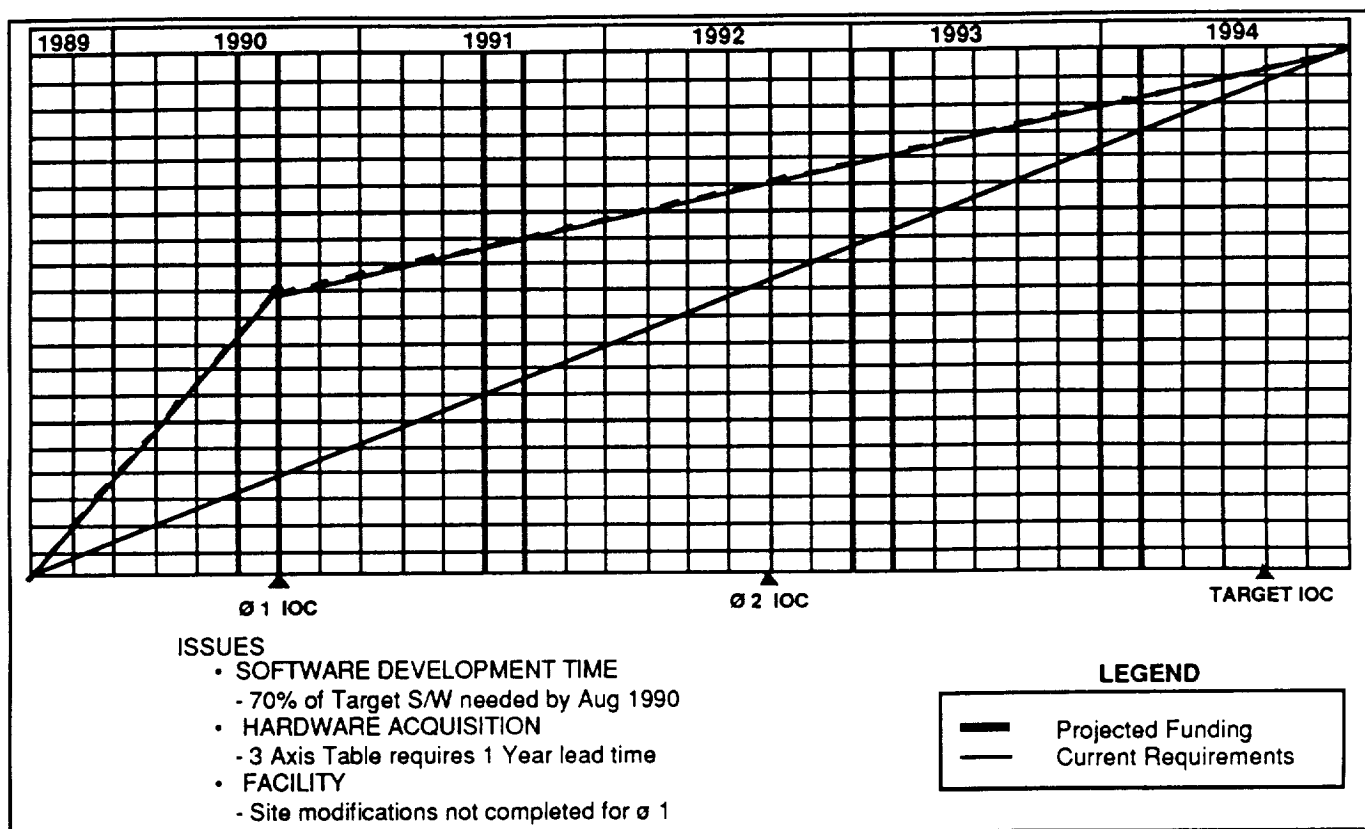


FIGURE 5.0-2 IMPLEMENTATION ISSUES

## 6.0 GBT ARCHITECTURE

This section covers both the hardware and software architectures of the GBT. It should be noted that the GBT has been structured to allow for a phased implementation of capabilities. The Target GBT is the full-up, third step configuration. It was designed to support the third HLCV reference configuration. This Fly Back Booster and Partially Reusable Cargo Vehicle must be accommodated in the Target GBT end-to-end real-time simulation.

### 6.1 GBT Hardware Architecture

Figure 6.1-1 shows the major functional hardware elements of the GBT. The following paragraphs will summarize each elements major functions. This will be followed by a more detailed discussion of each element.

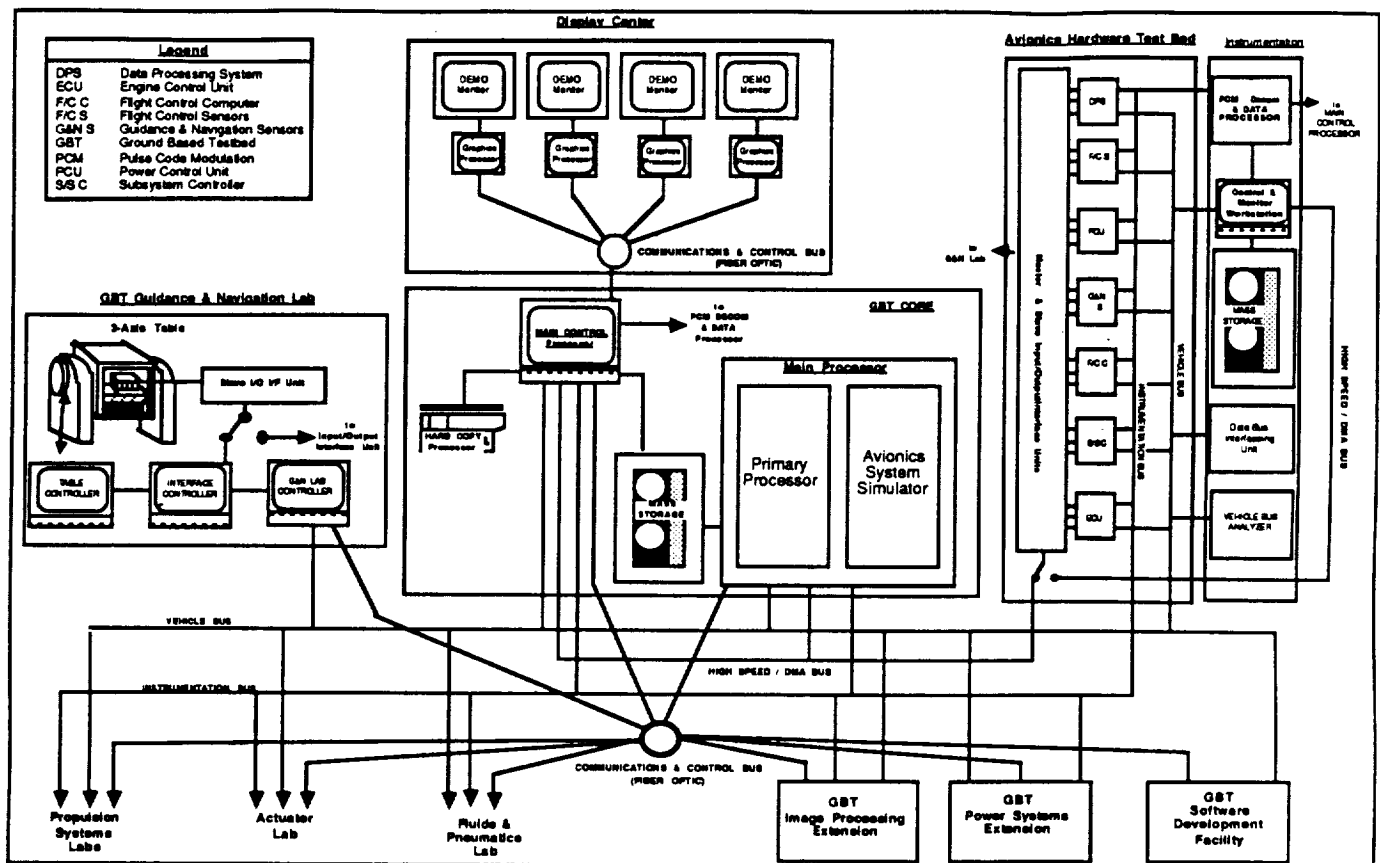


FIGURE 6.1.1-1. GBT TARGET CONFIGURATION

### 6.1.1 GBT Core

The GBT has been described as spanning the test continuum from pure simulation to hardware performance evaluation. Common to each extreme is a flexible, high through-put core processor. The GBT core has a main processor which is functionally divided into the primary processor and the avionics system simulator. The primary processor function includes running the simulation of the test vehicle dynamics, the mission environment and all other interfacing elements to the vehicle avionics system. The avionics system simulation function includes running the simulation of the test vehicle avionics system. This includes the monitor and control of all interfaces to real hardware being tested or run on the Avionics Hardware Test Bench.

Selection of the processor was one of the most important and far reaching design decisions of the study. The unit chosen combined an excellent cost to performance ratio with a software and hardware migration path capable of supporting the rapidly expanding simulation demands of the immediate future. Initially sized with a through-put in excess of 150 million instructions per second (MIPS), this expandable core processor has the software tools and I/O ports to support the GBT's current and future real-time simulation requirements.

The four other main elements of the GBT core are the Main Control Processor, Mass Storage Unit, Hard Copy Processor and Interconnecting Network/Bus Structure. The Main Control Processor is primarily tasked with the allocation and control of GBT resources. It controls most of the various buses and networks running throughout the GBT and supervises use of

the Mass Storage and Hard Copy Processor. While functionally a part of the GBT core, the Main Control Processor will probably reside in the Main Control and Demonstration Center.

The GBT Core functions and hardware specifications are described in detail in section 3.1.2 of the Preliminary Design Document. The GBT Core capabilities include:

- Interfaces to tie in special test facilities to test new technologies in avionics
  - Test image processing sensors
  - Test inertial units
  - Test actuators
  - Test fluids/pneumatics
- Support complete vehicle analog and discrete interfaces in core testbed.
- Processing capacity to simulate vehicle dynamics, environment, and all avionics models.
- Hardware to support test setup, monitor and control from a central location
- Instrumentation processing to support all instrumentation interfaces.
- Mass storage capable of storing system software and data, and continuous storage of test data
- Hardware to support off-line software development, post processing or demonstration.

#### 6.1.1.1 Main Processor

The GBT Main Processor primarily was designed and sized to handle a high fidelity real time simulation of the airborne systems, vehicle dynamics and flight environment of the most complex HLCV reference vehicle. Basic to its design is the ability to integrate system or subsystem level testing of real hardware into an end-to-end simulation so the performance of the hardware could be evaluated in its intended functional environment. Figures 6.1.1.1-1 and 6.1.1.1-2 show open loop hardware testing and closed loop hardware testing using the Main Processor.

The Main Processor must also be able to integrate other testing resources into the end to end simulations to increase the fidelity of the tests. The Guidance & Navigation Labs 3-axis table, as an example, allows more complete testing of vehicle inertial elements or complete guidance and control systems. The Main Processor would integrate the 3-axis table movements with the simulation time line events.

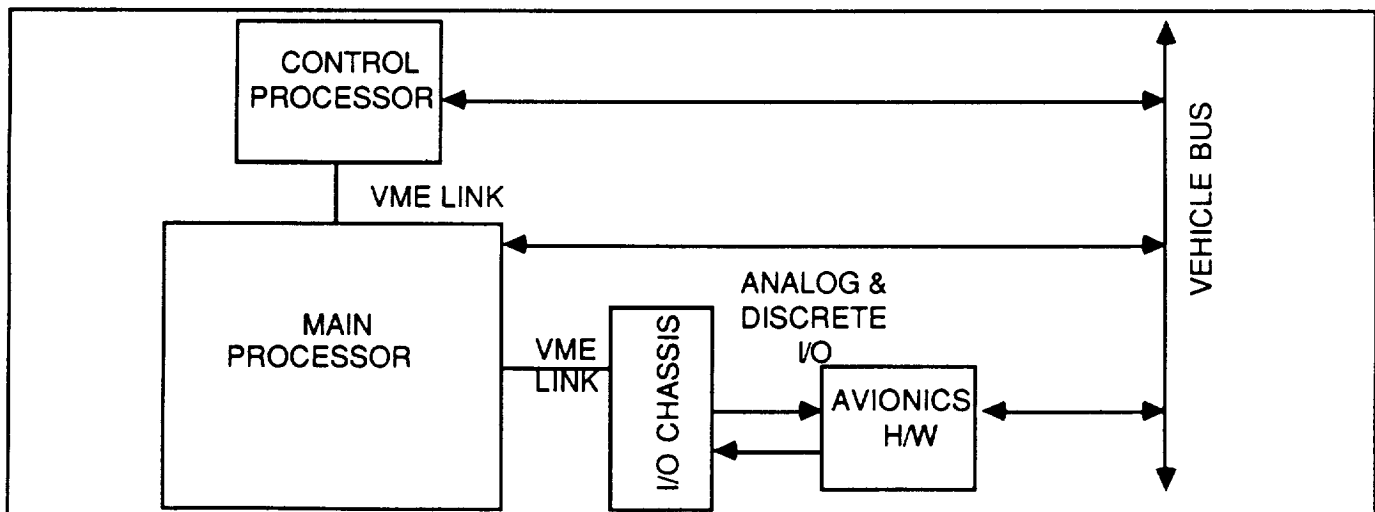


FIGURE 6.1.1.1-1. OPEN LOOP AVIONICS TESTING IN CORE FACILITY



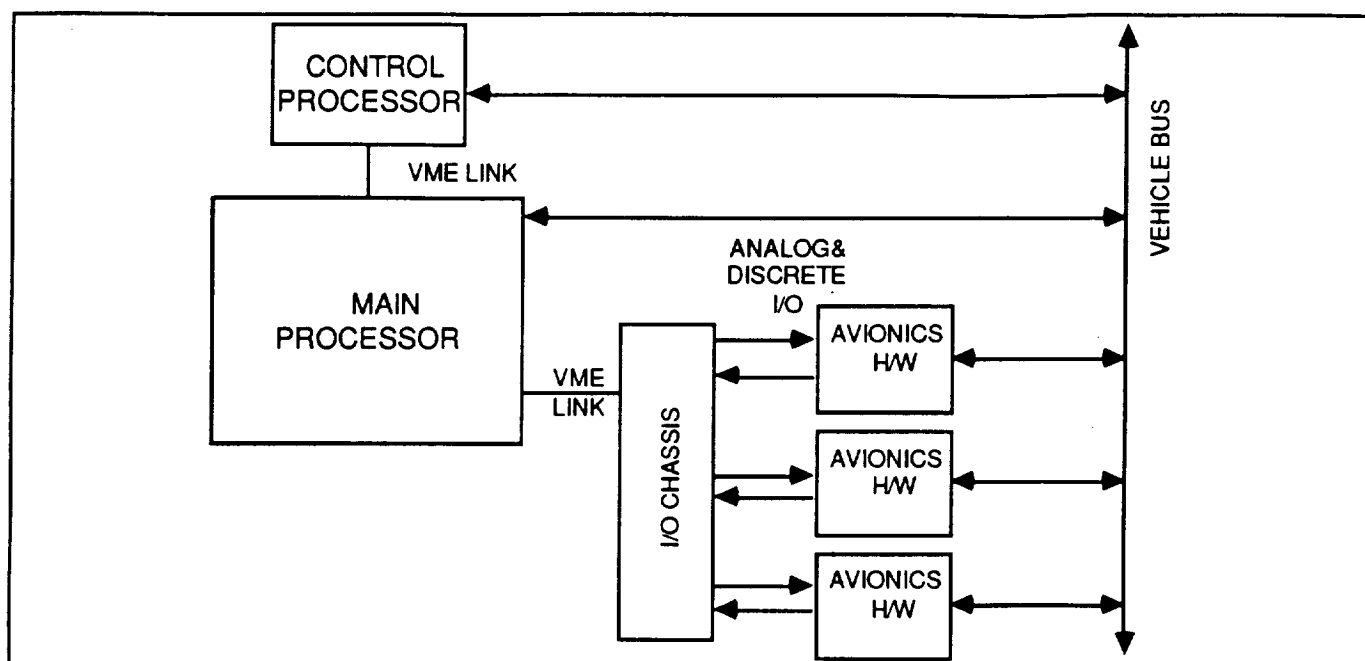


FIGURE 6.1.1.1-2. CLOSED LOOP AVIONICS TESTING IN CORE FACILITY

Core processing throughput sizing is shown in figure 6.1.1.1-3. The estimate of processor power and speed was made by extrapolation from a current simulation. A second method (see figure 6.1.1.1-4) based upon sensor input and other system operational parameters came up with a slightly higher figure. An analysis of the scope and nature of the simulation required to yield an end to end, real time simulation of the FRWB and PRCV indicated a minimum rating for the primary processor should be 150 MIPS. Product design practice would require a modular architecture in which the processor could be scaled up to meet the job.

**REQUIREMENT:** 150 MIPS - FOR REAL TIME SIMULATION OF HLCV ERA VEHICLES

**BASIS:** EXTRAPOLATION FROM CURRENT SIMULATION

- 6 DOF FLIGHT TRAJECTORY SIMULATION
  - 96 STATE VARIABLES
  - 20 MILLISECOND AUTOPILOT CYCLE
  - X10-20 INTERCYCLE
  - 2 NASTRAN MODES, BENDING MODE
  - AUTOPILOT FUNCTIONS, BENDING MODES, DISTRIBUTED AERODYNAMICS, MASS DISTRIBUTION UPDATING
- APOLLO 3000 WORKSTATION RUNS NON-REAL TIME SIMULATION IN 10 HOURS. REAL TIME: 270 SECONDS (REAL TIME SPEED UP: 133X FOR IDENTICAL TASK)
- INCREASED SCOPE OF SIMULATION
  - ADD 4 RATE GYROS
  - DISTRIBUTED ACCELEROMETERS
  - AIR DATA SENSORS
  - X5 PROPULSION SYSTEM INTERFACE
  - ADAPTIVE GUIDANCE
  - AUTOLAND
- INCREASE FOR GROWTH

FIGURE 6.1.1.1-3. CORE PROCESSOR THROUGH-PUT SIZING USING EXTRAPOLATION

MODULE	INSTRUCTIONS PER LOOP	COMP RATE (HZ)	INSTRUCTION PER SEC/LOOP	LOOP	INSTRUCTIONS PER SEC
RCS	124	500	62K	20	1.24M
ENGINE (THRUST)	114	500-10K	57K-1.14M	20	1.14M-22.8M
(FUEL USE)	27	500	13.5K	20	270K
GRAVITY	572	500	286K	1	286K
GRAVITY GRADIENT	181	500	90.5K	1	91K
VEH DYNAMICS	1481	500-10K	740.5K-14.8M	1	741K-14.8M
ATMOSPHERE	52	10-500	520-26K	1	26K
AERO FORCES	663	500	331.5K	1	332K
MASS PROPS (TANKS)	63	10-500	630-31.5K	20	13K-630K
(VEHICLE)	157	10-500	1570-78.5K	23	11K-550K
FUEL SLOSH	400	500	200K	1	200K
BODY BENDING	1000	500	500K	1	500K
TOTAL W/O ACTUATOR AND I/O					4.9M-41.7
I/O	50	500	25K	500	12.5M
ACTUATORS	399	10000*	4M	40	160M
TOTAL					117.4M-214.2M

NOTE: HIGHER COMPUTATION RATES ARE FOR HIGH FIDELITY EVENTS SUCH AS VEHICLE SEPARATION.

FIGURE 6.1.1.1-4. CORE PROCESSOR THROUGHPUT SIZING USING SPECIFIC SYSTEM DESIGN (SINGLE VEHICLE, MEDIUM FIDELITY, 3-STRING AUTOPILOT AVIONICS ON HOT BENCH)

Figure 6.1.1.1-5 shows the basic architecture of this expandable parallel processor. Eight RISC processor sets will be connected to the backplane bus whose current, Phase I rating is 64 million bytes per second (MB/sec). The RISC processors are rated at +20 MIPS each. An internal global memory is also connected to the MC bus (backplane bus). Input/output flows from the backplane bus through a VME I/O module in the Phase 1 configuration. Each of these VME buses currently are rated at +26 MBS average. The number and performance of the VME buses will be increased in subsequent phases. The main processor design easily accommodates upgrades to backplane global memory processor and I/O modules.

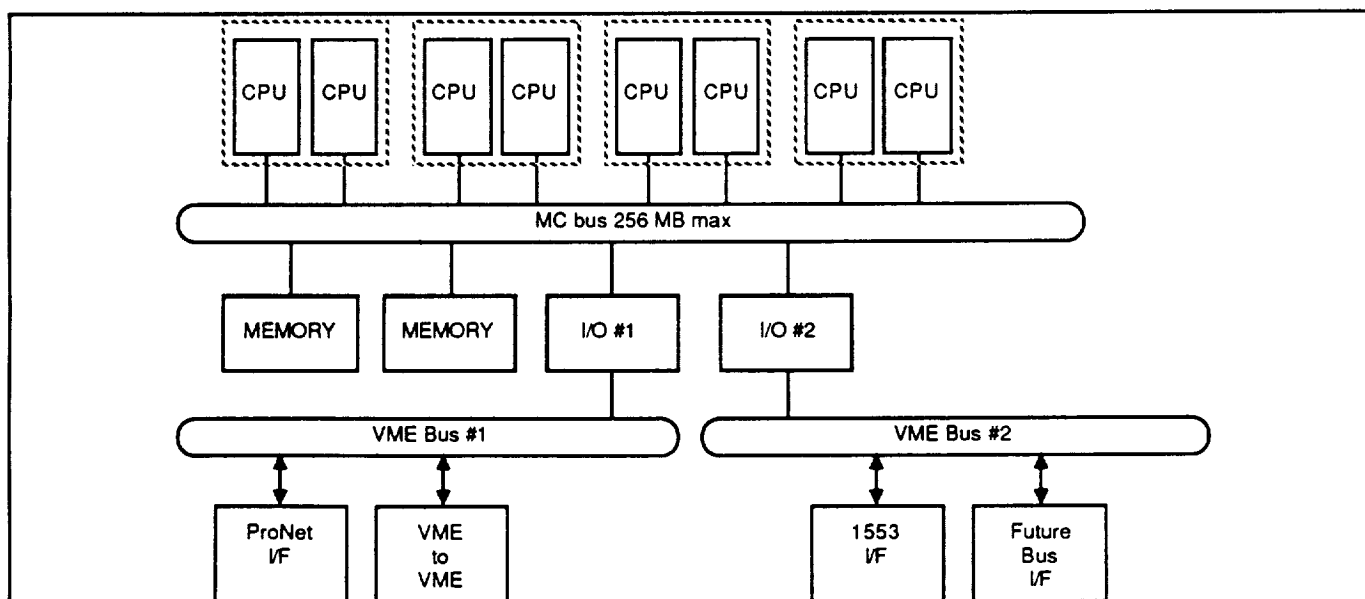


FIGURE 6.1.1.1-5. MAIN SIMULATION PROCESSOR

### 6.1.1.2 Main Control Processor (MCP)

The main control processor, though functionally part of the GBT core, will probably be in the Main Control and Demonstration Center. Designed to control and monitor overall GBT operations, this parallel processor shares the open architecture and highly compatible features of the main processor. Figure 6.1.1.2-1 shows the Control Processor initial, Phase 1 configuration. Four 25 MHz, 68030 CPU's are teamed with four 68882 floating point co-processors to provide the necessary processing power to control the Phase 1 GBT. A 16 Mb RAM provides the initial "fast memory" necessary to support Phase 1 processing levels. The RAM is expandable to 120 Mb and is connected to the backplane "memory" bus.

Control and display functions are accommodated by the MCP's independent graphics subsystem. It supports a 19" high resolution monitor for high quality color graphic displays. Keyboard and mouse inputs are provided. Storage and retrieval of data are provided by disk and tape controllers. Storage and retrieval of data are provided by disk and tape controllers.

Input/output is a key function of the MCP. Two independent VME bus systems are provided. Interface modules provide access to the GBT ProNet 80, 1553 and orbiter buses/networks. A separate multibus interface accommodates the GBT Ethernet.

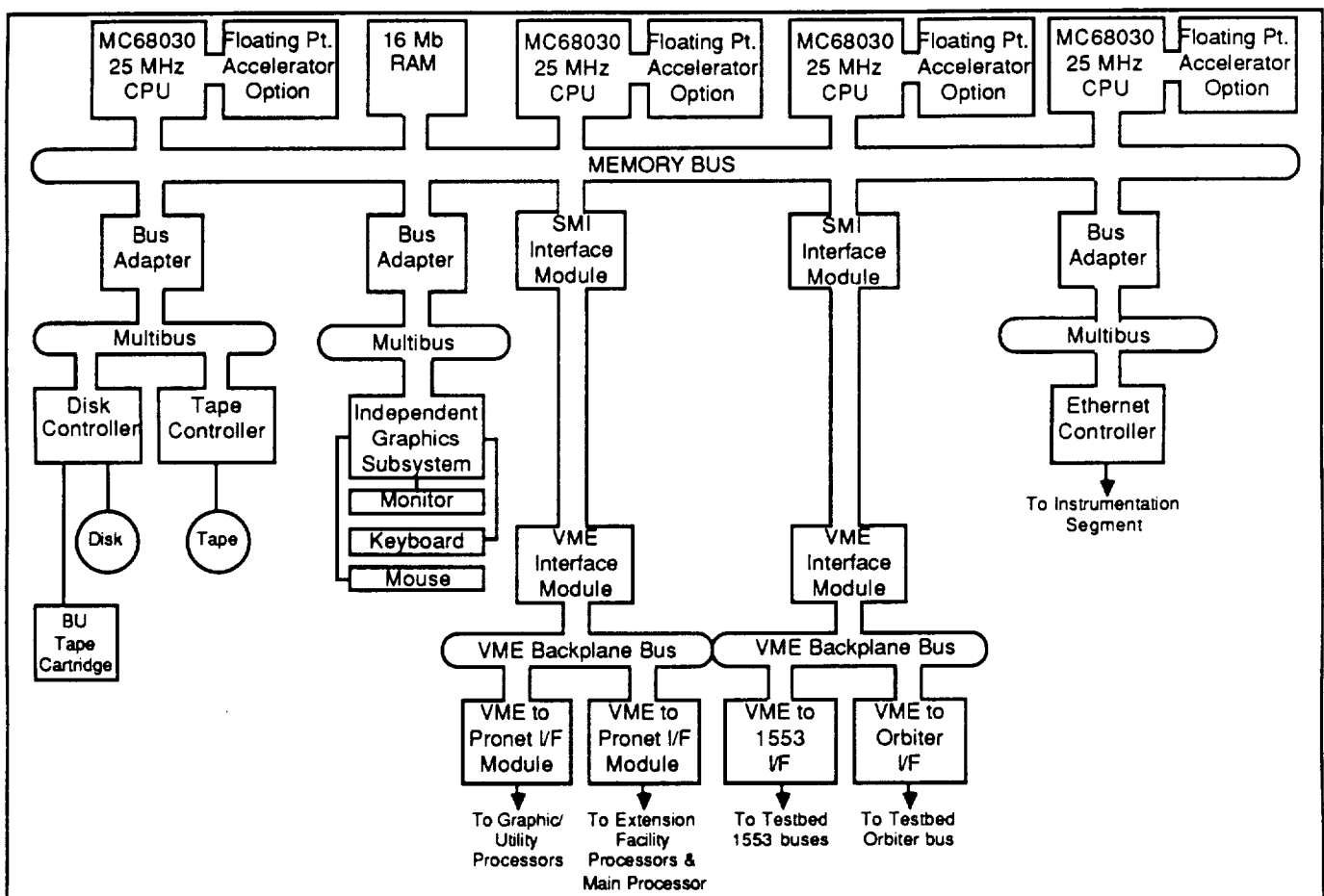


FIGURE 6.1.1.2-1. MAIN CONTROL PROCESSOR (MCP)

### 6.1.1.3 Mass Storage

The GBT Phase 1 Mass Storage includes a 1 GByte 8" hard disk system, 2-1/2" SCSI tape units and a 1/4" 150 MB 5.25 cartridge backup tape unit. These three types of storage units were selected for specific functions. The 8" hard disk provides rapid access to currently required programs and data. The tape provides storage for more periodic data retrieval and storage where access time is not important. The quarter inch cartridge tape is used for data backup as well as being a convenient and popular medium for introducing new software into the system.

### 6.1.2 Main Control and Demonstration Center

Within this element rests the primary control and allocation of all the GBT resources. Central to its function is the Main Control Processor that is linked to all the available resources by an extensive inter / intra lab communications network. The Main Control Center and Demonstration Center are collocated because of their complementary functions. The Demonstration monitors may be used to supplement the status displays available to the core's Main Control Processor. The graphics processors will also supplement the Main Control Processor in controlling parallel operations going on within the GBT.

The Demonstration Center primarily consists of four graphics processors driving four large screen monitors. The graphics processors are used to develop display and other support type graphics. Working with the large screen monitors, the processors can reproduce demonstration graphics depicting anything from real-time test parameters to reproduction of demonstration graphics. Figure 6.1.2-1 shows one conceptual layout of the Main Control and Demonstration Center.

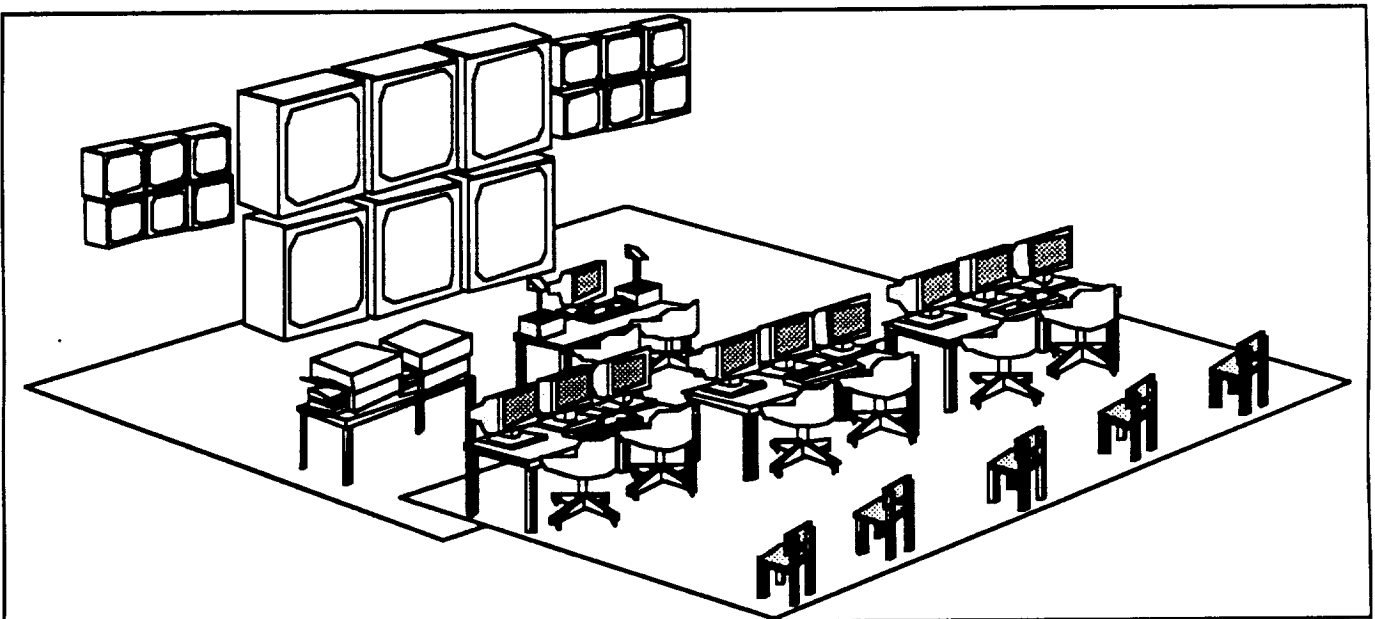


FIGURE 6.1.2-1. MAIN CONTROL & DEMONSTRATION CENTER

### 6.1.2.1 Main Control Processor (MCP)

This unit was discussed previously in connection with its control functions centered about the GBT Core. The MCP plays a key role in the control and monitoring function of the Main Control and Demonstration Center. During demonstrations the MCP can be used to coordinate the multimedia presentations. Live and pre-stored material can be routed to the large presentation monitors, combining real time test demonstrations with the necessary introductory and reference information. During demonstrations, the MCP is used to set up the data paths from the GBT resources to the Graphics Processors in the Demonstration Center via the communications and control buses. Data from the Mass Storage, Video Recorders, and the Instrumentation Resource Lab can be accessed and/or routed over the High Speed/DMA and other GBT buses.

### 6.1.2.2 Graphics Processors

The four graphics processors are intended to perform several functions. Basically, they must be able to process raw data into pre-determined graphic displays. They can be able to develop the graphics software to facilitate this processing. The graphics processors must also be able to support two different graphic outputs and have limited video processing capabilities.

During demonstrations and integrated GBT operations, the graphics processors can be used as auxiliary control terminals or display units. Data routed from the MCP can be displayed on the Graphic Processor screen or routed to the demonstration monitors. MCP control can be supplemented by the graphic processor when properly configured by the MCP.

The Graphic Processors are designed to develop the graphic displays used for lab control monitoring and for demonstrations. In this role the graphic processor can operate independently or tie in the necessary resources to test the function of the graphic software being developed. The communications and control bus will be used to handle this function.

The graphics processors will, in later phases, be able to do a limited amount of video processing. This processing will permit the combining of pre-recorded video from a VCR with computer generated graphics. This "GenLoc" function will permit the easy production of video presentations of GBT test results viewable via any standard VCR.

### 6.1.2.3 Demonstration Monitors

Figure 6.1.2-1 shows a conceptual layout of a Main Control and Demonstration Center in which the large demonstration monitors are pictured. The GBT Target Configuration calls for four of these large, 44" minimum, color monitors. These units must be able to accommodate standard color TV composite, RGB, and the "multi-sync" outputs from the graphic processors.

### 6.1.2.4 Hard Copy Processors

These units will initially be laser and standard dot matrix printers used to support the development of GBT software and graphics. In later phases, scanners and color printers will be added to support the demonstration function.

### 6.1.2.5 Graphics/Video Processors and Storage Units

Initial graphics and video processing will be restricted to standard video cartridge recorders capable of editing and recording standard broadcast video and the composite output from the graphics processors. If GBT demonstrations require production of more elaborate presentations, commercial, broadcast quality video processing equipment may be considered to preserve the quality of the finished video presentations.

### **6.1.3 Avionics Hardware Test Bench**

The Avionics Hardware Test Bed is the third major segment of the GBT Target Configuration. It contains the interfacing units, busses and harnesses necessary to accommodate the GBT Benchmark hardware. The benchmark hardware is a collection of current avionics units which, when connected to the required interfacing harness, comprise a fully functional avionics system. It provides a real world performance standard to which the candidate hardware can be compared. The Avionics Hardware Test Bed therefor facilitates development and evaluation of new avionics systems, and components by providing a high fidelity, native environment in which they can be tested.

#### **6.1.3.1 Hotbench**

The GBT Hotbench is designed and configured to include hook-up with a unique LRU box. Benchmark tests can be performed to compare system operation or box to box operation. Boxes may be compared to software models. The hotbench is programmable via programmable digital to analog and analog to digital converters. Unique harness and cable will need to be furnished or built to plug-in unique boxes. Hotbench support software will permit tailoring of signal characteristics by adjusting skew and delay of the interfacing signals.

The Phase 1 hotbench design will have all the harness and cabling to facilitate Shuttle-C (Option C) hardware. Cable style, length and impedance shall be as close to actual as required or possible. When unique or option C hardware is not available software simulation may be run to emulate that hardware. The general path to the vehicle bus is via programmable A/D and D/A converters. Discretes in many cases will be shared between either hardware or other remote voter units (RVU).

### **6.1.4 Instrumentation**

The Instrumentation segment is a subset of the Avionics hardware test bed that permits local control and monitoring of the test bed hardware or units under test. It functionally duplicates an instrumentation ground station and is equipped to analyze vehicle bus traffic.

### **6.1.5 Guidance & Navigation Lab**

The GBT G&N area of the lab will contain a dedicated 3-axis table with a thermal chamber. The INU will be mounted and used for closed loop system evaluation and system operation. The LRU 1553 outputs and discretes pass through table slip ring connectors and are put onto the vehicle bus. Unit accelerations will be simulated via software. For three string configurations, two other strings will be simulated to allow operation and testing of such functions as fault isolation redundancy management and system functions checkout. Hardware will be completely simulated as well. Benchmark testing will be available with the G&N section of the lab. Box to box comparisons may be made open loop or in an overall closed loop system performance mode. During open loop test the local local processor will be able to do ATP type test as well as check both the navigation and flight control section of

the INU. Data collection will be available locally to evaluate LRU during ATP and envelope tests.

### 6.1.6 Software Development Facility

A major design driver is the architecture of the user friendly software that yielded the efficient and highly compatible interface for potential users. The cost effectiveness of GBT usage rests squarely on its accessibility and its ability to accommodate several tasks in parallel. This translates to a modular set of software tools, tailorable to specific applications and executed with data that bounds the required performance regimes. The tailoring and selection of appropriate performance data is accomplished by a menu driven linkage process. The Software Development Facility will initially be located in the Main Control and Demonstration Facility while the basic GBT operational and benchmark software is being integrated. As the GBT phases into operation, the function of this element will shift to the primary user interface. It will become the site where users will assemble the modularized software tools and simulations into the desired testing regimes. The Software Development Facility will also host the building of the demonstration graphics.

### 6.1.7 Power Systems Extension

This GBT extension will be capable of testing new technologies in Power Systems components and architectures. This Phase 2 extension will support not only the normal evaluation of candidate power system sources and architectures, but will be focused on EMA power supply development and testing.

### 6.1.8 Navigation Aid and Image Processing Extension

This GBT extension is scheduled for Phase 2 implementation. It is designed to provide developmental support as well as verification of autonomous rendezvous and docking aids in the near term and to support the development of approach and landing systems for the far term Flyback Booster.

#### AUTONOMOUS ATTITUDE AND POSITION SENSORS

- CCD, SCANNING LASER, GPS, STAR TRACKER/REFLECTOR, HORIZON SENSOR
- APPLICATION: ENABLES RENDEZVOUS AND DOCKING, AUTOLAND
  - BENEFITS: OPERATIONAL FLEXIBILITY, AUTONOMY, SAFETY
- LAB SUPPORT REQUIREMENTS:
  - 3-AXIS TABLE
  - FLAT FLOOR
  - HIGH DEFINITION IMAGING SYSTEM
  - STAR TRACKER
  - GPS AIRBORNE AND SYSTEM EMULATORS
- OVERALL LAB BENEFITS
  - CAN DEMONSTRATE AVIONICS SUBSYSTEMS AND OPERATIONS FOR
    - RENDEZVOUS AND DOCKING
    - APPROACH
    - LANDING
- AUTOLAND
  - DEMO FAILURE TOLERANCE, OVERRIDE CAPABILITIES
  - DEVELOP OPERATIONAL REQUIREMENTS, PROXIMITY OPERATIONS
  - DEFINE AVIONICS REQUIREMENTS

FIGURE 6.1.8-1. IMAGE PROCESSING/NAV AID EXTENSION SUMMARY

Two, Phase 2 functions were detailed within the HLCV 2nd Quarterly review, September 1988. They are: (a) a moving scene generator, and (b) precision stellar star generator.

#### 6.1.8.1 Scene Generation

The moving Scene Generator would work together with the existing six DOF flat floor. A camera would be mounted and fly into a moving scene. Image recognition and image manipulation would be possible. Surface could be changed rapidly. Figure 6.1.8.1-1 shows the scene generator can be used with both the flat floor and the G&N Lab.

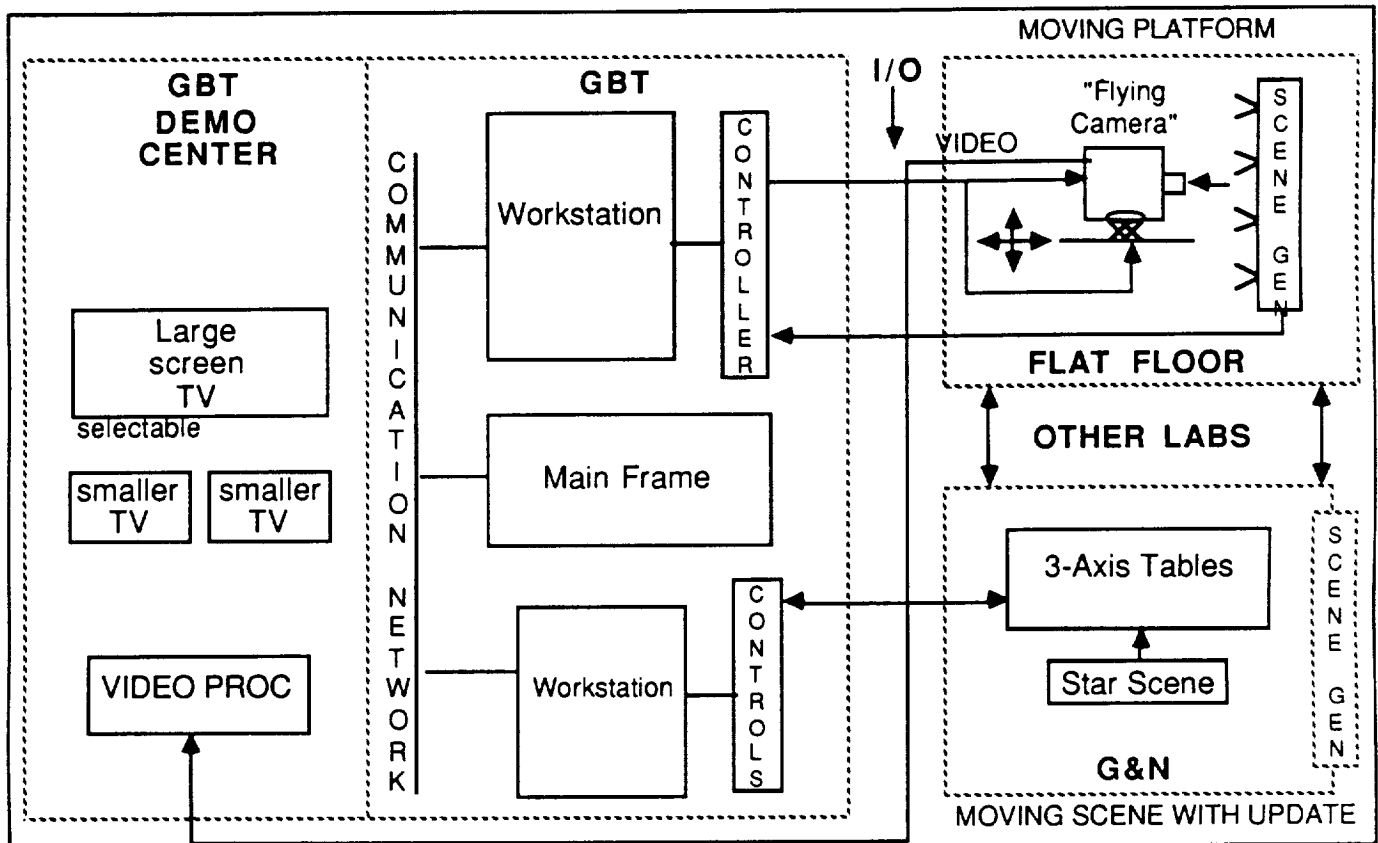


FIGURE 6.1.8.1-1. RENDEZVOUS AND DOCKING/TERMINAL LAND DEMO

#### 6.1.8.2 Stellar Projection

The G&N will be outfitted with a dark room enclosure for projection and an open ceiling to view actual stars. A combination of both fixed and slow moving scenes, such as a Space Station docking port, will allow evaluation and test integration of items such as Position/velocity updates; Terminal navigation; Image recognition; Docking/rendezvous; and Re-entry. These are shown in Figure 6.1.8.2-1.



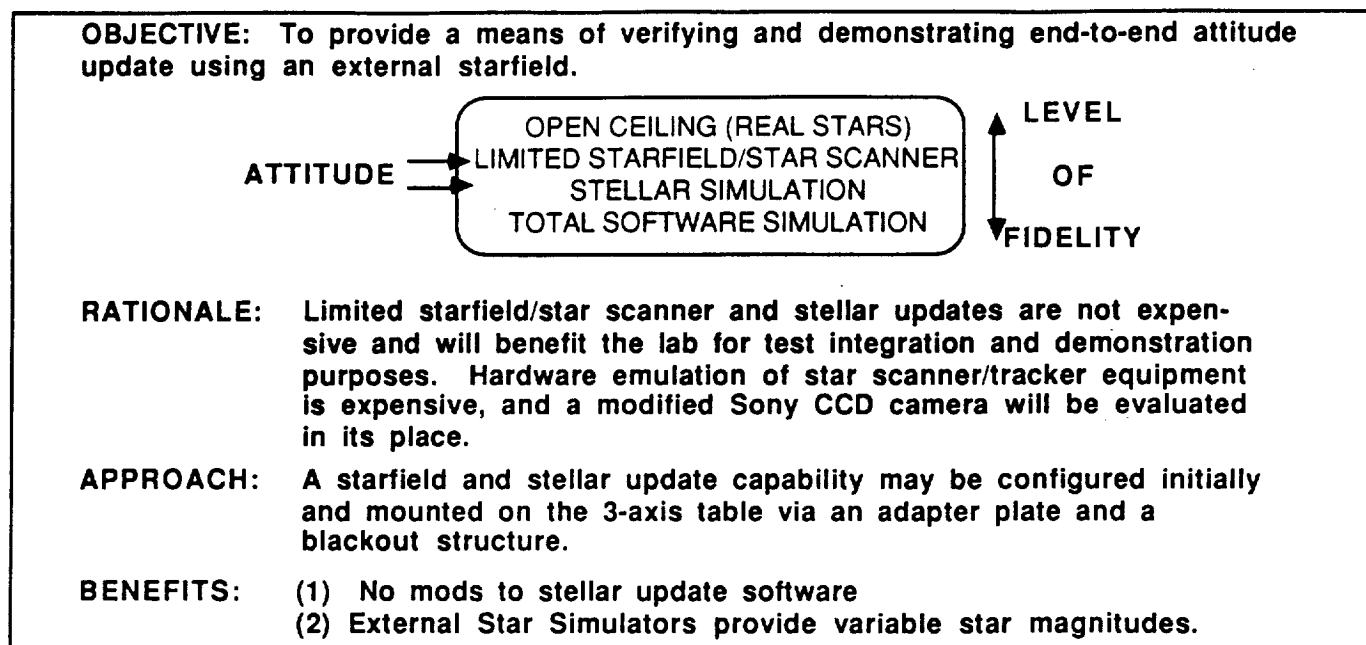


FIGURE 6.1.8.2-1. LIMITED STARFIELD / STAR SCANNER

## 6.2 Phase 1 Configuration

The initial Phase 1 GBT configuration is scheduled to be operable in August of 1990. Figure 6.2-1 lists several of the support capabilities to be demonstrated at that time. SDV-2ES is the first HLCV reference vehicle and functionally equivalent to Shuttle-C. Its mission profile is depicted in figure 6.2-2. Four software mission phase models are required for the Phase 1 IOC. They include Launch, Ascent, Orbital maneuvering and a ballistic type of controlled entry.

Benchmark hardware includes the equivalent of 1 string of the Shuttle-Derived Vehicle avionics system. Limited interface capabilities on the Avionics hardware testbed can accommodate only two "boxes". (This capability will be expanded substantially during Phase 2).

Figure 6.2-3 shows a vehicle processing throughput as a function of time. These projected throughput levels added to the requirements for vehicle dynamics and mission environment require the core processor to equal or exceed its projected 70+ MIPS configuration for Phase 1.

Flight operations for Shuttle-C, shown in figure 6.2-4 were used in projecting the throughput requirements.

The Phase 1 GBT Configuration is pictured in figure 6.2-5. Many target capabilities are absent. Among these are the interface provisions to many of the resource labs and extensions. The G&N Lab is the exception where a full link is present. The Propulsion Lab also will have a port available on the fiber optic communications and control bus.

1. MISSION MODELS - (2DV-2ES)
  - LAUNCH
  - ASCENT
  - ON ORBIT (MANEUVER)
  - ENTRY
2. SYSTEM TEST
  - SDV REFERENCE SYSTEM
    - IMU
    - COMPUTER
    - DAS
    - MDU
    - RDU
    - MDM \* INTERFACE ONLY
    - EIU \* INTERFACE ONLY
3. OUTSIDE RESOURCES
  - SSME LAB INTERFACE
  - EMA (OPTION)

FIGURE 6.2-1. PHASE 1 CAPABILITIES AND CONSTRAINTS

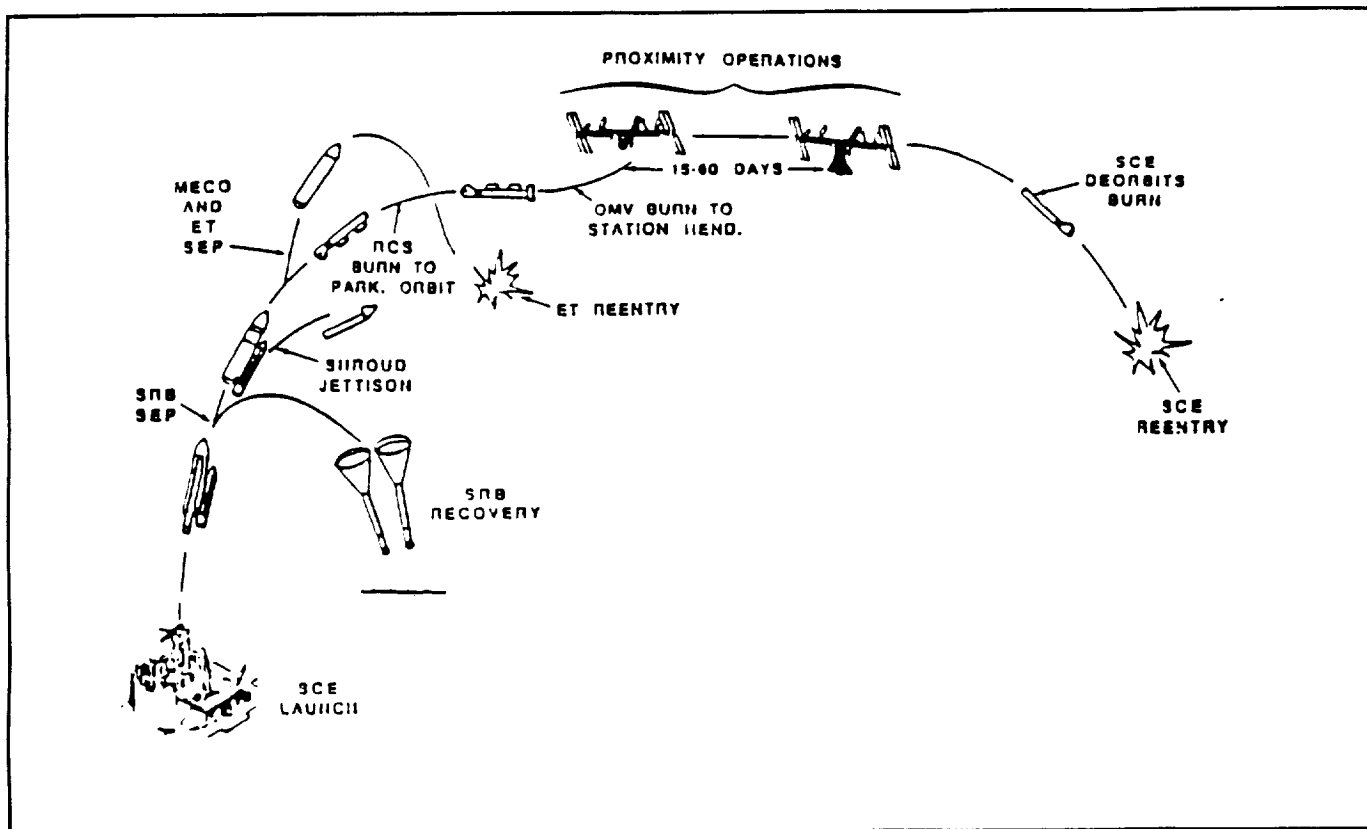


FIGURE 6.2-2. MISSION PROFILE

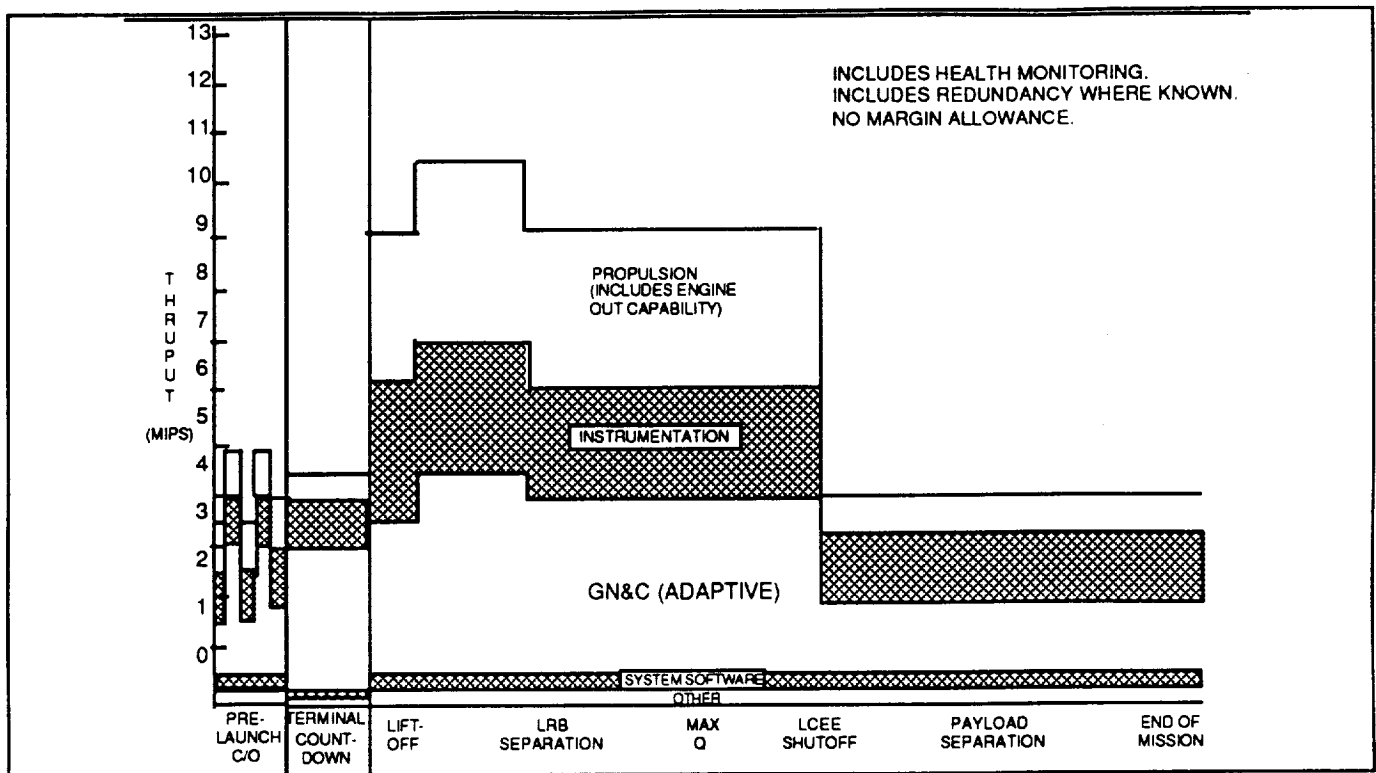


FIGURE 6.2-3. PHASE 1 VEHICLE PROCESSING TIMELINE

- AUTONOMOUS FLIGHT CONTROL TO ORBITAL INSERTION, CIRCULIZATION AND DEORBIT
  - SIMPLEX SHUTTLE-C MISSION CONTROL CENTER
  - BASIC SHUTTLE-C AVIONICS FOR THIS FUNCTION
  - PRECURSOR MISSION PLANNING (SIMPLEX), PAYLOAD INTEGRATION TO CARGO BAY BY SHUTTLE-C
- ORBITAL DEPLOY MISSIONS (E.G., PLANETARY AND OTHER FREE FLYING SPACECRAFT)
  - PAYLOAD DEVELOPER RESPONSIBLE FOR OPERATIONS FROM POCC AFTER PAYLOAD SEPARATION
- SPACE STATION MISSIONS
  - PRECURSOR MISSION ( $\Delta$  ON ORBIT) PLANNING DONE AS PART OF OMV/SS ACTIVITY
  - OMV/SPACE STATION CONTROL CENTER RESPONSIBLE FOR RENDEZVOUS, PROX-OPS, DOCKING, MISSION OPERATIONS (E.G., ASSEMBLY) AND DEORBIT FROM SS/OMV CONTROL CENTER OR MULTI-PURPOSE CONTROL CENTER
  - VERY LIMITED "KIT ON" SHUTTLE-C DELTA AVIONICS INCLUDING BATTERIES, ETC.

FIGURE 6.2-4. FLIGHT OPERATIONS

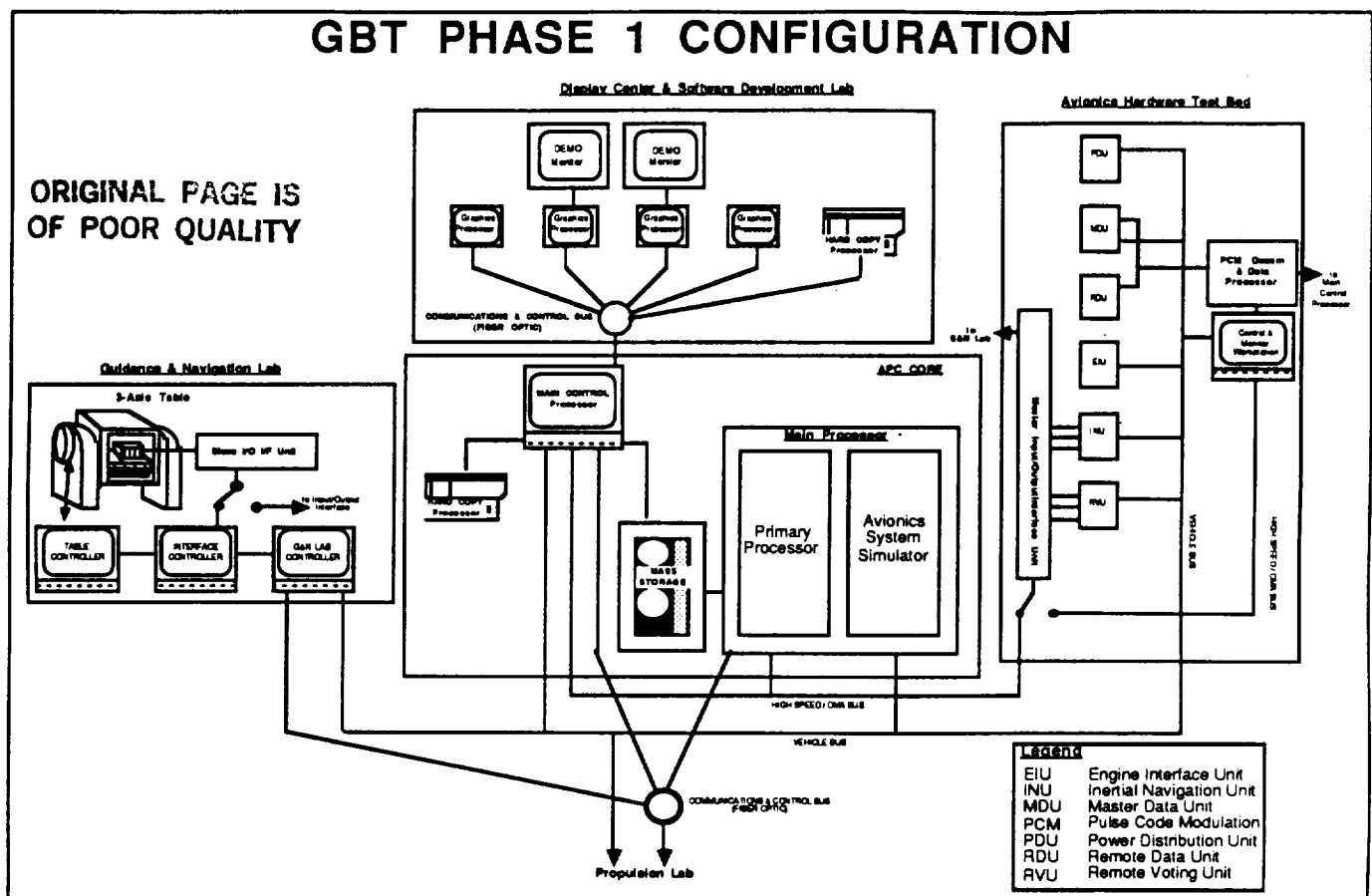


FIGURE 6.2-5 GBT PHASE 1 CONFIGURATION

The GBT Core Processor is only partially filled, giving it a throughput of about 70+ MIPS. The software will be developed initially on the Graphic Processors residing in the display center. The function of the display/demo center and software development will be performed at that location. The benchmark hardware used in the avionics hardware testbed will probably be a single string of the Shuttle-C architecture. The interfacing capabilities of the Master I/O unit will accommodate only the equivalent of an Inertial Navigation Unit (INU) and a Remote Voting Unit (RVU) simultaneously.

### 6.3 Phase 2 Configuration

The Phase 2 GBT capabilities and constraints are listed in figure 6.3-1. Vehicle simulation capabilities now include the ALS Booster and Core. The overall simulation capability is more generic than before, with the complete range of software modules completed. The Core Processor has been fully expanded to the target configuration, permitting complete end-to-end, real-time simulations. Rendezvous and Docking and Precision Entry simulations will also be possible in Phase 2.

Hardware testing of a complete "string" of avionics equipment will be possible with the avionics hardware test bench. A more complete set of generic software models will be available for use.

Figure 6.3-2 depicts the Phase 2 GBT configuration. Note the changes in the hardware test bed and display center. Now a separate software development facility is available and links are available to a variety of labs and extensions.

1. MISSION MODELS - SHUTTLE-C, ALS, (GENERIC)
  - LAUNCH
  - ASCENT
  - ON ORBIT (STV) MANEUVER, RENDEZVOUS & DOCKING
  - ENTRY (CONTROLLED AND PRECISION)
2. SYSTEM TEST - SHUTTLE-C, ALS, STV (GENERIC)
  - G/NS
  - F/CS
  - F/CP
  - DAS
  - PC
  - S/SC
3. OUTSIDE RESOURCES
  - SSME LAB INTERFACE
  - ACTUATOR LAB

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FIGURE 6.3-1. PHASE II CAPABILITIES/CONSTRAINTS

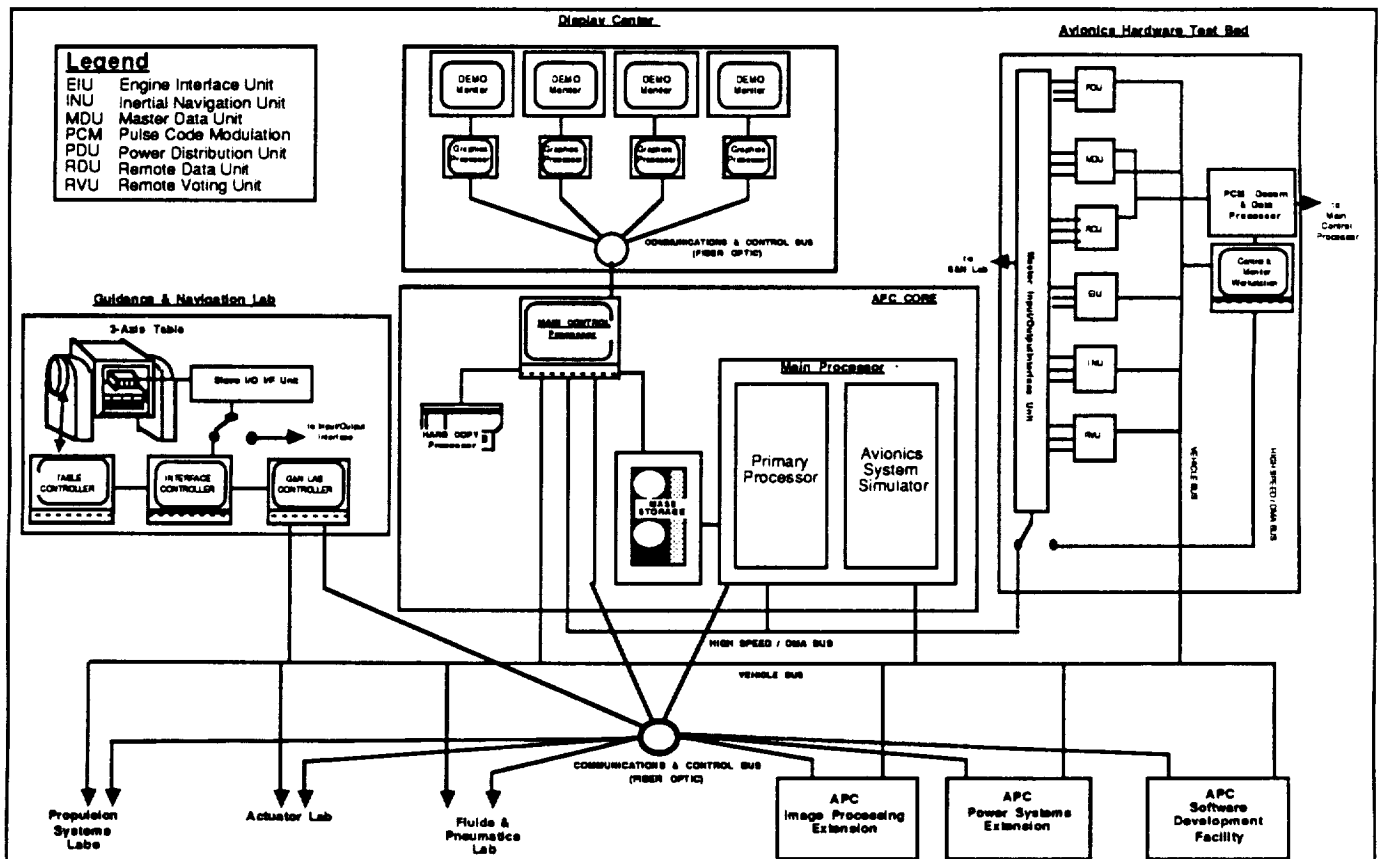


FIGURE 6.3-2. GBT PHASE II CONFIGURATION

## 6.4. GBT Software Architecture

### 6.4.1 Software Architecture Characteristics

#### 6.4.1.1 Real-time Simulations Multi-Processor Based

The software supports real-time, multi-processor based simulations of existing or new unmanned vehicles including Shuttle-C, Centaur, OMV, STV, and ALS. The software is structured to take advantage of the multi-processor host computer to meet the simulation speed requirements. Additionally, the software is structured to allow variable frame-times for the individual software modules. An example of the multi-processor, variable frame time structure is shown in figure 6.4.1.1-1.

#### 6.4.1.2 Phases of Flight

The software is structured to allow the capability to simulate any phase of flight including pre-launch, ascent, on-orbit, re-entry and landing. This capability allows the simulation of both individual flight phases and an integrated mission consisting of multiple flight phases.

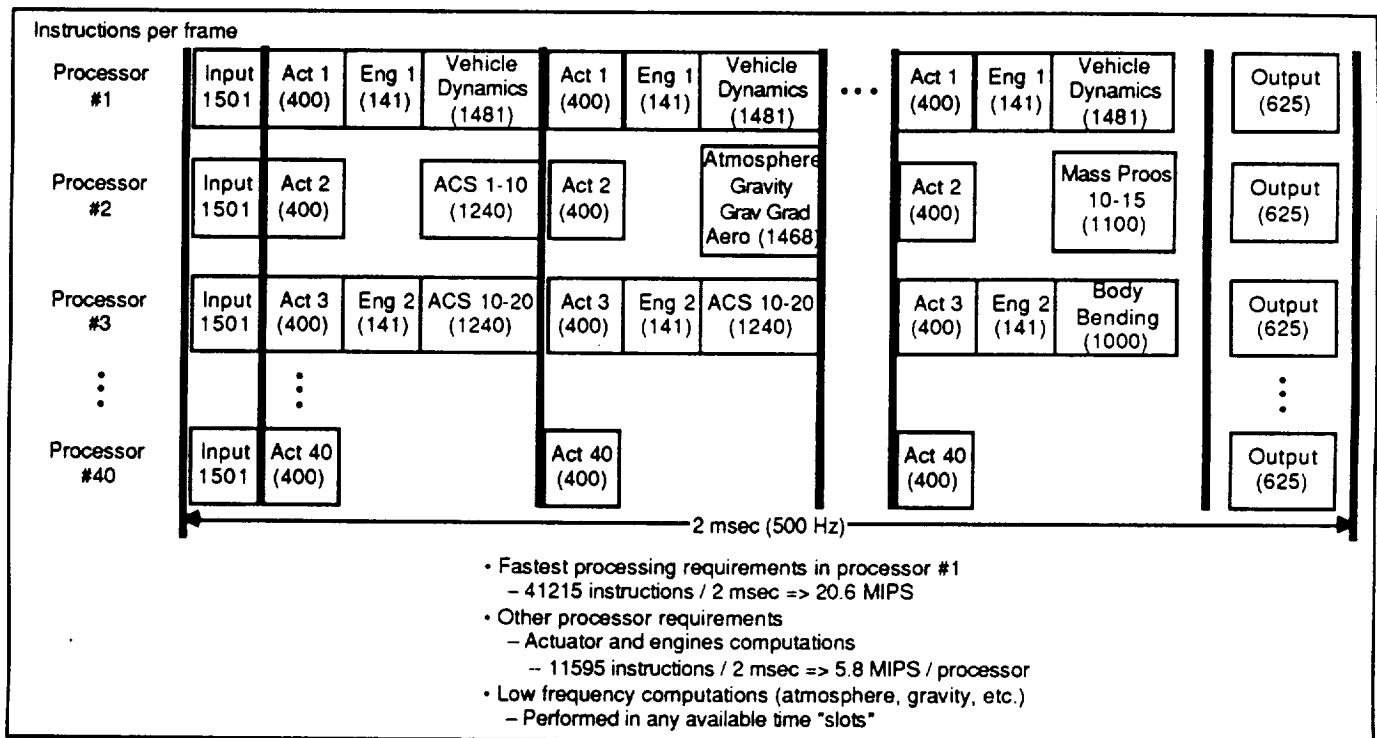


FIGURE 6.4.1.1-1. TYPICAL PARALLEL-PROCESSING TIMING DIAGRAM (SINGLE VEHICLE, MEDIUM FIDELITY, 3-STRING AUTOPILOT AVIONICS)

#### 6.4.1.3 Integration of Avionics Hardware Into Real-Time Simulations

The software provides interface routines to drive appropriate I/O hardware. These routines and associated I/O hardware have the capability of reading from and writing to existing and/or new avionics hardware in a real-time manner. The avionics hardware to be supported includes Guidance and Navigation systems, Controls interface, data acquisition system and power systems.

#### **6.4.1.4 Real Time Simulation of Avionics Hardware**

The software modules perform real-time and non-real-time simulations of existing or new avionics hardware. These modules are in varying levels of fidelity to meet necessary real-time requirements. The software allows the simulation of multi-string avionics hardware by the use of multiple software modules and/or actual hardware.

#### **6.4.1.5 Fault Insertion Capabilities**

The software allows for the simulation of vehicle/subsystem faults and avionics hardware faults. Manual, pre-canned and random fault-insertion capabilities are provided.

#### **6.4.1.6 Stand-Alone Avionics Hardware Testing**

The software provides the capability to perform stand-alone testing of existing and/or new avionic hardware. This capability is independent of the main simulation, though individual simulation routines are used when necessary. The stand-alone testing has an acceptance test procedure (ATP) type of format, providing stimuli to the hardware and monitoring appropriate hardware responses. The software is structured to allow for a variety of test lengths and includes automatic, semi-automatic and manual test capabilities. The semi-automatic and manual test modes are such that an operator can manually select which hardware inputs to stimulate and which hardware outputs to monitor. Additionally, the operator may manually start the execution of any pre-programmed automatic test sequences.

#### **6.4.1.7 User Friendly Interface**

The software provides a user-friendly interface based on a tree-structure and utilizing multiple window displays.

#### **6.4.1.8 Multiple Users**

The software provides multiple user capability. This capability allows separate users to perform simultaneous independent simulations, LRV tests and software development within the performance constraints of the host computer, bus traffic and I/O constraints and avionics hardware availability.

### **6.4.2 Specific Simulations Provided for Phase 1**

The following specific, full-up simulators shall be provided:

- Shuttle-C trajectory simulation
- Shuttle-C engine simulation
- Electromechanical actuator simulation
- Others TBD

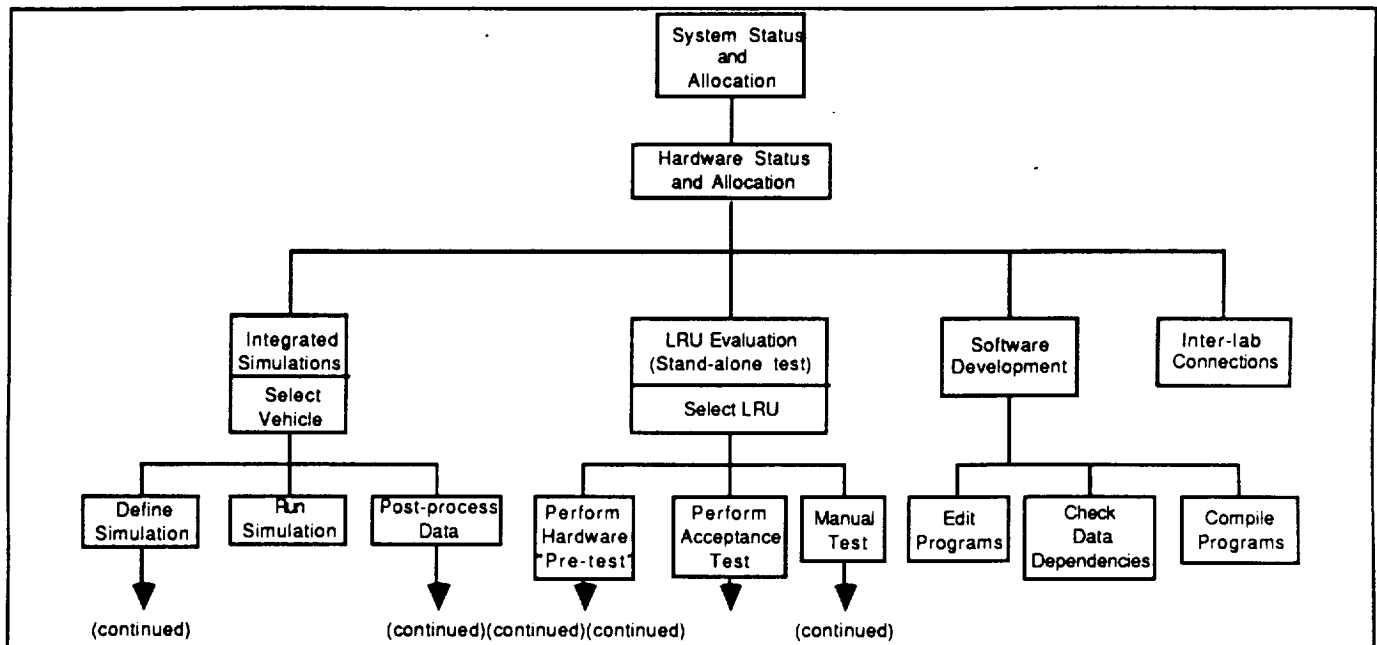
### **6.4.3 Lab Configuration Software**

#### **6.4.3.1 Program Status**

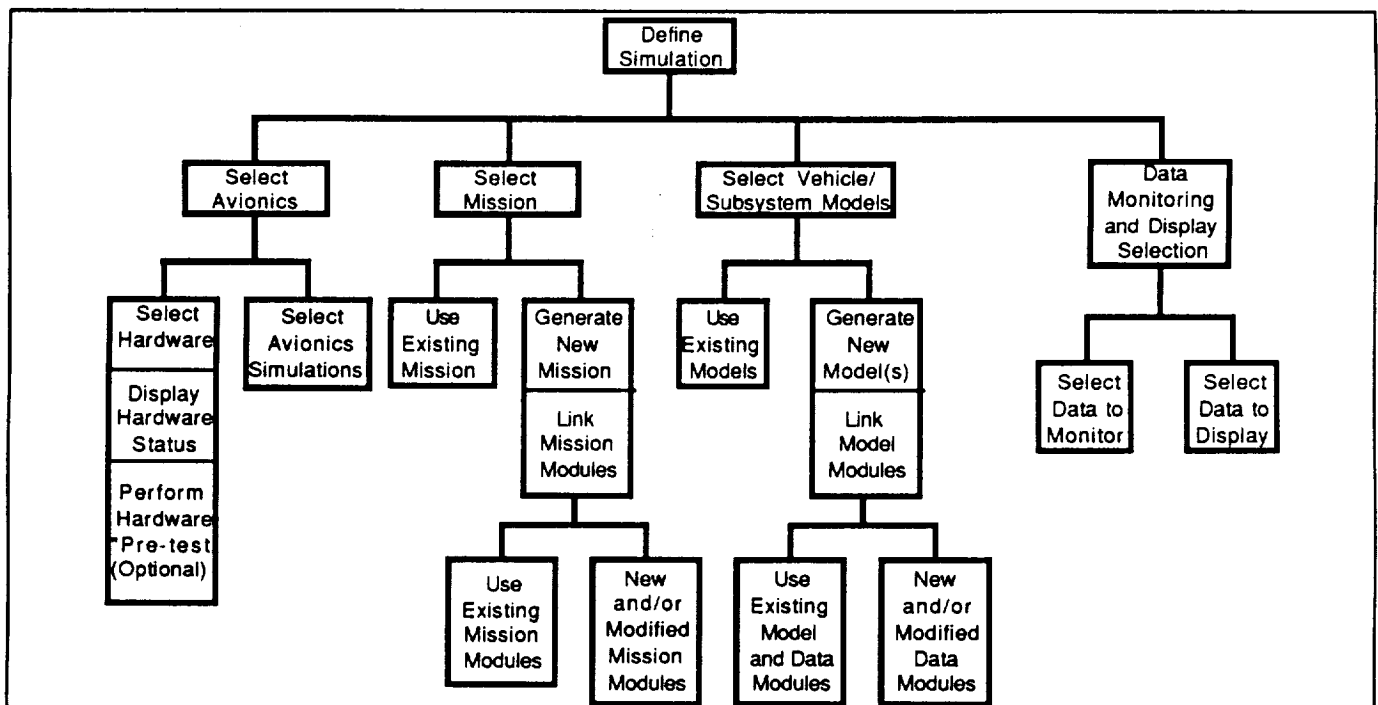
The lab configuration software maintains a consistent structure during the development of the lab. The structure allows for a flexible simulation development and execution environment. This structure is based on the use of generic simulation modules and application-specific data files.

### 6.4.3.2 Tree-Based Multi-Level Menus

The lab configuration software shall incorporate the tree-structured elements shown in Figure 6.4.3.2-1, -2 and -3.

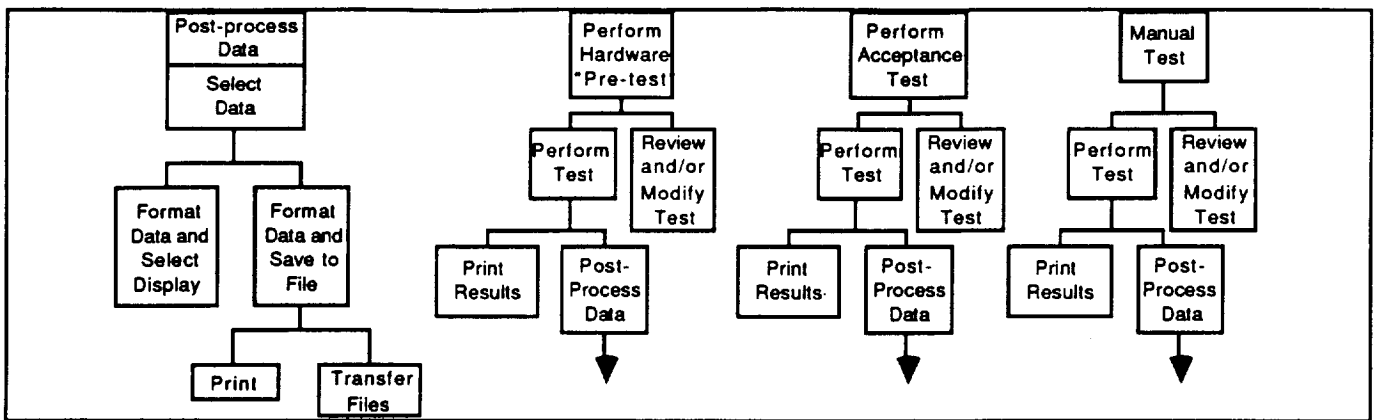


**FIGURE 6.4.3.2-1. LAB CONFIGURATION SOFTWARE: GBT TARGET AND PHASE 1 DESIGNS - PROGRAM / MENU STRUCTURE**  
**NOTE: EACH BLOCK REPRESENTS AN INDIVIDUAL MAIN PROGRAM MODULE AND MENU**



**FIGURE 6.4.3.2-2. LAB CONFIGURATION SOFTWARE: GBT TARGET AND PHASE 1 DESIGNS - PROGRAM / MENU STRUCTURE (CONT)**  
**NOTE: EACH BLOCK REPRESENTS AN INDIVIDUAL MAIN PROGRAM MODULE AND MENU**





**FIGURE 6.4.3.2-3. LAB CONFIGURATION SOFTWARE: GBT TARGET AND PHASE 1 DESIGNS - PROGRAM / MENU STRUCTURE (CONT)**

**NOTE: EACH BLOCK REPRESENTS AN INDIVIDUAL MAIN PROGRAM MODULE AND MENU**

### 6.4.3.3 Elements

All program modules and menus are generic, i.e., the menu structure changes for different simulations and lab configurations. All elements are data driven either by user defined data files and/or user commands from the keyboard. The software design goal is to not require new software modules to be written (coded) as a new simulation is defined.

### 6.4.4 Simulation Models

#### 6.4.4.1 Mission/Vehicle/Environment Models

Simulation software is provided to support avionics testing in simulated ascent, orbital and controlled reentry phases. The fidelities and frame types of the software modules are variable and selectable using data files. As a minimum, software modules are provided to support components shown in figure 6.4.4.1-1.

#### SIMULATION MODULE DESCRIPTIONS

- 6 DOF DYNAMICS - PROPAGATES 6 DOF DYNAMICS FOR EACH VEHICLE
- MASS PROPERTIES - CALCULATES TIME VARYING VEHICLE MASS PROPERTIES BASED ON FUEL CONSUMPTION AND VEHICLE STAGING / SEPARATION EVENTS
- AERODYNAMICS - CALCULATES AERODYNAMIC FORCES USING LOWER AND UPPER ATMOSPHERES AND REENTRY MODELS
- BODY BENDING - CALCULATES VEHICLE BENDING EFFECTS BASED ON VEHICLE STIFFNESS AND/OR BENDING MODES
- SLOSH - CALCULATES FUEL SLOSH EFFECTS ON VEHICLE ACCELERATIONS AND CG
- MAIN ENGINES - CALCULATES ENGINE THRUST AND FUEL USE BASED ON LOW AND HIGH FIDELITY ENGINE MODELS
- REACTION CONTROL SYSTEM (RCS) - CALCULATES RCS EFFECTS AND FUEL USE BASED ON LOW AND HIGH FIDELITY RCS AND RCS FLUIDS MODELS
- ACTUATORS - CALCULATES ACTUATOR POSITIONS BASED ON LOW AND HIGH FIDELITY ELECTRO-MECHANICAL ACTUATOR MODELS
- THRUST VECTOR CONTROL (TVC) - CALCULATES THRUST VECTOR FORCES BASED ON ENGINE THRUST, ACTUATOR POSITIONS, AND VEHICLE BENDING EFFECTS
- ENVIRONMENT - CALCULATES ATMOSPHERIC PARAMETERS BASED ON ALTITUDE, SIMULATES DISTURBANCES AND WIND EFFECTS
- HARDWARE / SOFTWARE INTERFACES - PROVIDES I/O ROUTINES FOR HARDWARE IN THE LOOP, I/O SIMULATIONS FOR SIMULATED HARDWARE

**FIGURE 6.4.4.1-1. PHASE 1 SIMULATION MODELS: - MISSION/VEHICLE/ENVIRONMENT MODELS****6.4.4.2 Avionics Simulation Models**

Simulation software is provided to functionally simulate avionics hardware. The software models are structured to allow for the testing of redundancy concepts such as multiple sets of avionics (hardware and/or software simulation), cross-channel communications, synchronization and shielding. Software modules are provided to support the components shown in figure 6.4.4.2-1.

**DESCRIPTIONS**

- NAVIGATION - SIMULATES INERTIAL SENSORS AND FLIGHT CONTROL PROCESSOR FUNCTIONALITY AND INTERFACE ELECTRONICS
- VOTING LOGIC - SIMULATES VOTING LOGIC FUNCTIONALITY AND INTERFACE ELECTRONICS
- DATA ACQUISITION - SIMULATES DATA ACQUISITION, REDUCTION AND TRANSMISSION AND INTERFACE ELECTRONICS
- ENGINE CONTROLLER - SIMULATES ENGINE CONTROLLER FUNCTIONALITY AND INTERFACE ELECTRONICS
- RGU AND AA - SIMULATES RATE GYROS AND ACCELEROMETERS
- CROSS-CHANNEL COMMUNICATIONS - PROVIDES CROSS-CHANNEL DATA LINK BETWEEN AVIONICS MODULES (HARDWARE AND/OR SOFTWARE MODELS)
- SYNCHRONIZATION AND SKEWING - SYNCHRONIZES WITH HARDWARE AND PROVIDES ARTIFICIAL SKEWING TO SOFTWARE MODELS
- INSTRUMENTATION - SIMULATES DATA NECESSARY FOR DAS OPERATION

**FIGURE 6.4.4.2-1. PHASE 1 SIMULATION MODELS: - AVIONICS SIMULATOR MODELS****7.0 HLCV GROUND BASED TESTBED FACILITIES**

The detailed facility requirements for each major GBT element are contained in the Preliminary Design Document, (PDD). These requirements cover the basic power, space and environmental needs of the major GBT elements but don't address the overall Lab layout. This section will summarize the recommendations from which the layout will be determined. Fuller definition of the layout was deferred pending definition of the actual GBT site and the modification possible with the funds allotted.

**7.1 Location**

Key to the utility of the Ground Based Testbed is its proximity to the resources it must draw upon and serve. Early utilization will be enhanced if it is close to existing testing facilities. As the GBT primary processor and attendant communication networks are brought onto line, closed loop simulations, involving one or more adjacent labs will become possible. Early attention to those existing laboratory resources that would most benefit from the added GBT capabilities should be a factor in selecting the GBT location.

A second factor involves the GBTs potential to become an effective and convenient demonstration facility. This potential will obviously be enhanced if the GBT is in close proximity to the existing conference and administrative sites. Figure 7.1-1 shows the candidate GBT site and the adjacent test and administrative facilities.

## 7.2 GBT Layout

Figure 7.2-1 shows the basic Building 4476 1st floor plan. The area designated for the GBT is shown in figure 7.2-2.

A change to this area is already in work, but the completion dates do not support the current Phase 1 IOC date of August 1990. This proposed change has three options. The "A" option was used in this study.

A general GBT layout is shown in Figure 7.2-3. Detailed layouts of existing labs at GDSS were used as a basis for this preliminary plan. Volume II contains these layouts and a list of the "lessons learned" during their implementation and use.

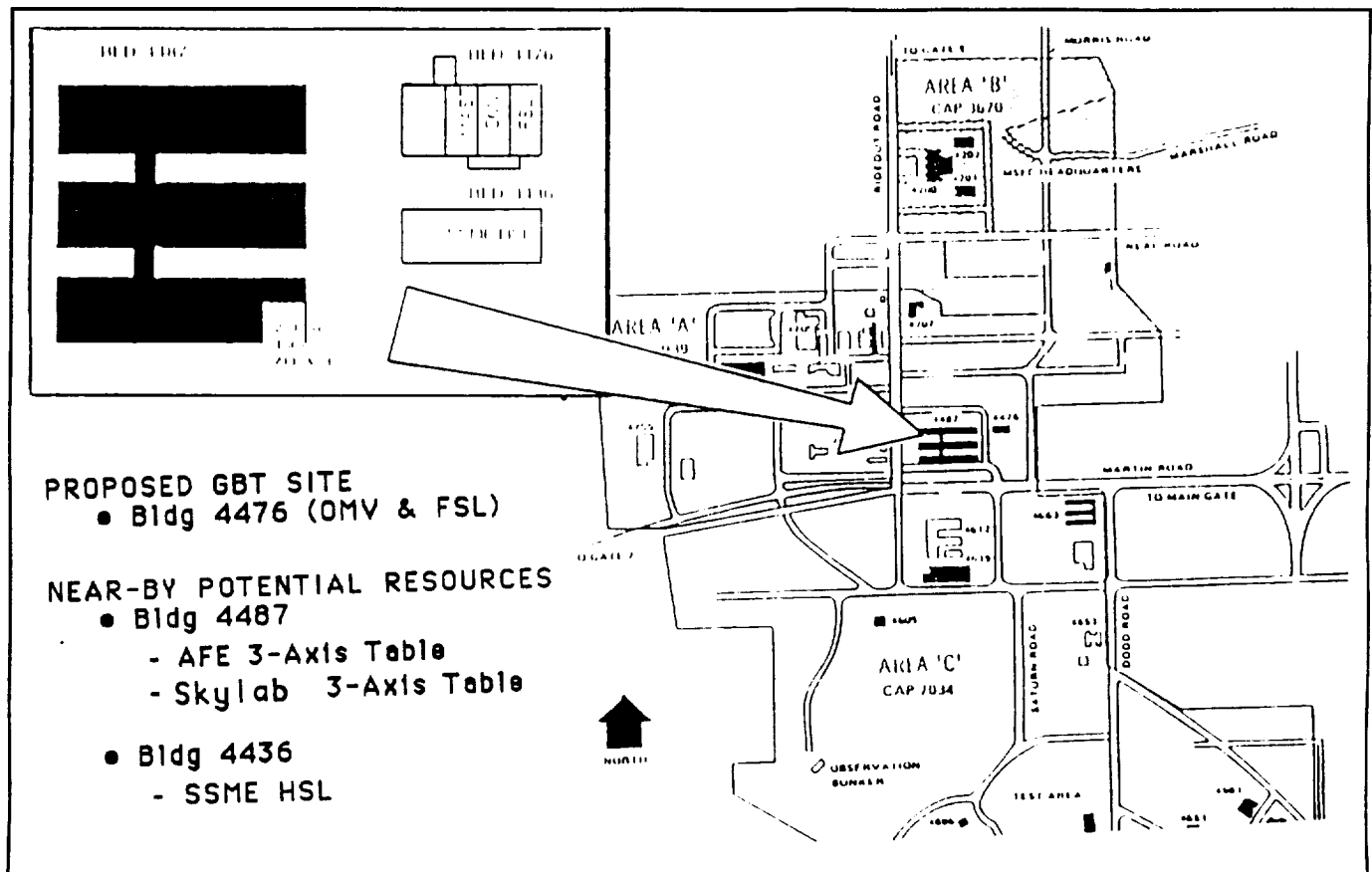


FIGURE 7.1-1.. GBT FACILITY LOCATION

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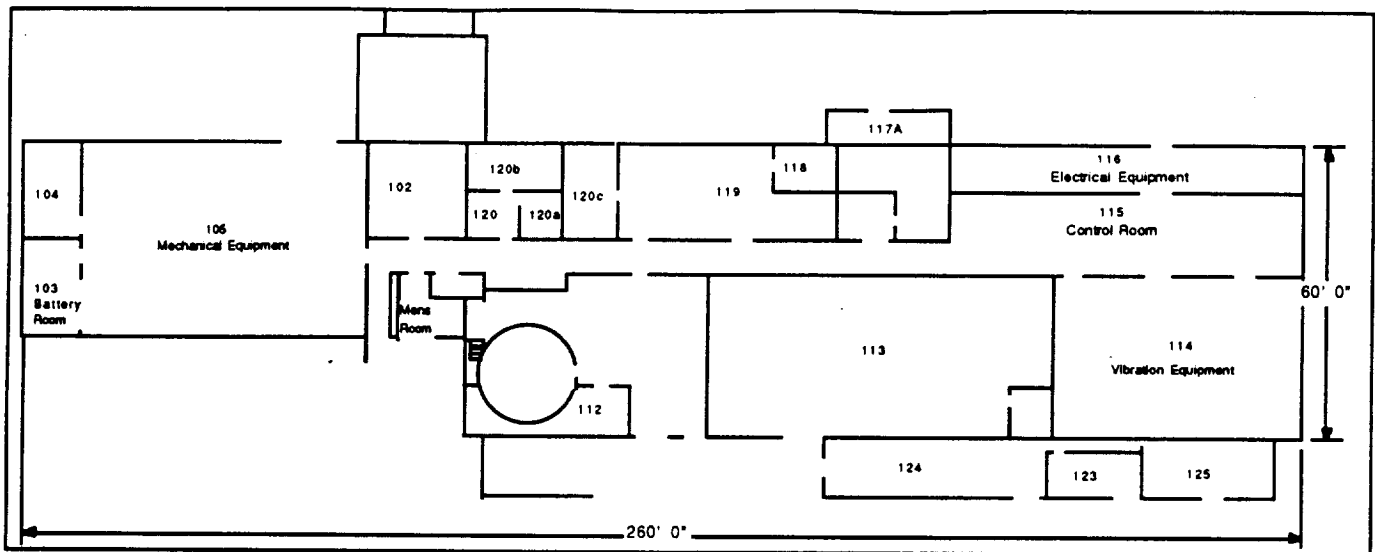


FIGURE 7.2-1. BUILDING 4476, MSFC

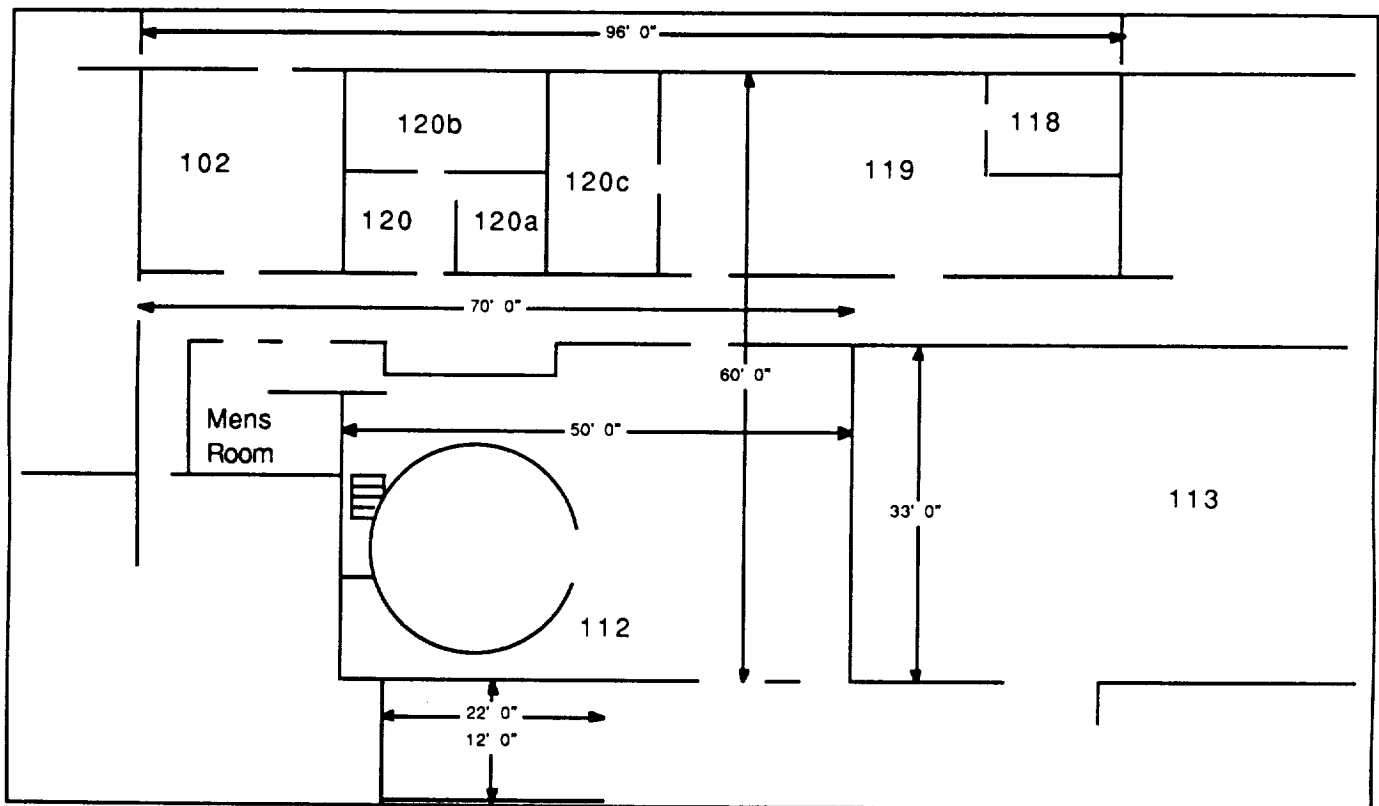


FIGURE 7.2-2. FIRST FLOOR

TABLE 2.2.2-1

NO	DESCRIPTION	RATIONALE
1	Southern High Bay Extension with 2 large access doors.	1. Provides access to High Bay and staging areas #1 & #2
2	Northern G&N Lab Extension	2. Accommodates G&N labs & provides North Star LOS. Provides easiest method to provide isolation pads for 3 axis table.
3	Northern High Bay Extension	3. Accommodates future "flow through" processing of modules & staging.
4	Mezzanine Modification	4. Optimizes main processor areas to resources (shortens distance to Hot Bench & staging areas by placing main processor on mezzanine.)

### 7.2.3 Proposed GBT Space Allocations

The original Target GBT floor plan approached 10000 square feet and featured a two story layout. The candidate site offered about one third of the space unmodified. Optional add-ons bring the usable space to around 5000 square feet and optimizes the usefulness of the 2nd floor area.

#### 7.2.3.1 Demonstration, Control and Processing Centers

Figure 7.2.3.1-1 shows a general spatial allocation of the mezzanine. The GBT Primary Processor, Control Processor, Mass memory and hard copy printing devices will be housed in the GBT Processing Center upstairs and adjacent to the Demonstration & Control Center. Both areas will have independently controllable environments designed to properly accommodate the data processing equipment, staff and visitors. Attention will be given to provide a view of high bay and staging area operations. Windowed partitions will be utilized to provide the designed view of the Processing Center and downstairs working areas while maintaining the controlled equipment. The Demonstration area will accommodate up to 20 visitors in a design which permits a good view of the large screen monitors, projection screens and main control console. Individual control of the Demonstration Center temperature and lighting is imperative.

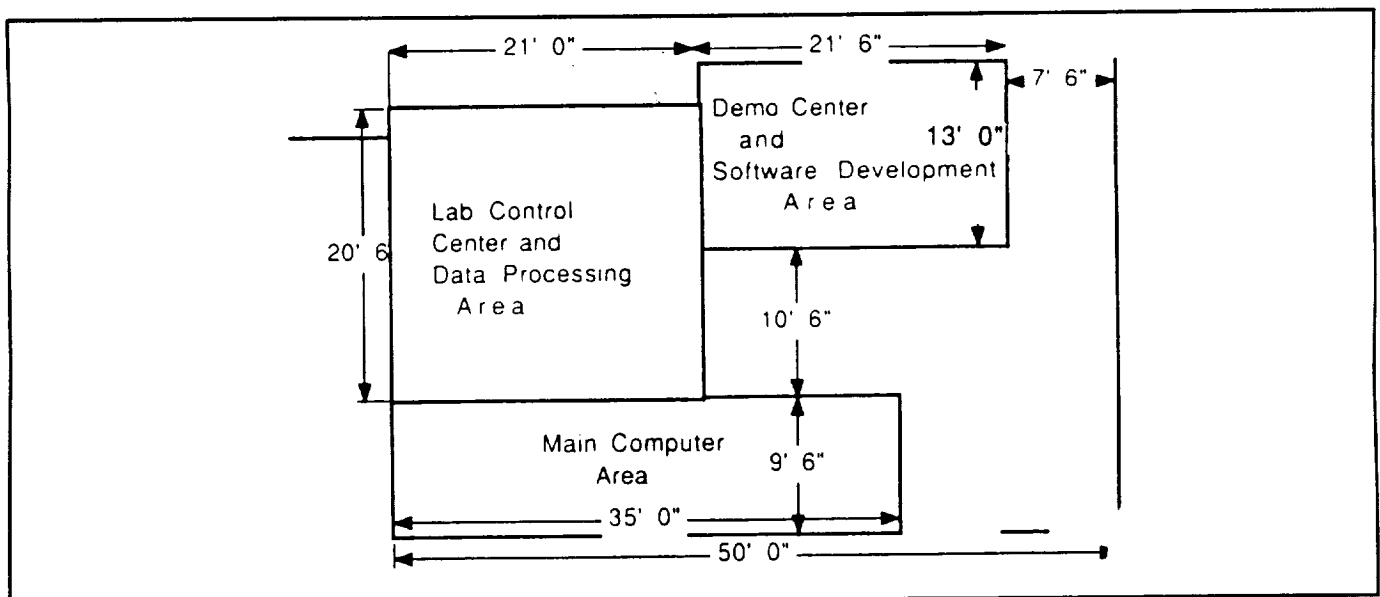


FIGURE 7.2.3.1-1 MEZZANINE LAYOUT

Safety provisions for rapid egress from the mezzanine require two stairways. Provisions to protect the Primary Processing Center from fire and intrusion should be provided. A Halon system should be investigated.

#### **7.2.3.2 Avionics Hardware Testbed (Hot Bench) and Staging Area**

Basic to the design of the GBT is its capability to evaluate candidate hardware in a closed-loop, simulated operational environment. The Target configuration will have the ability to interface with prototype hardware at both the box and system level. A Primary full capability test bed will be supplemented with staging area equipment capable of preliminary open loop and closed loop testing. The staging areas will enable a parallel and more efficient use of the GBT facilities. The large roll up type of doors will facilitate easy access to the two staging area test stations. The staging areas are adjacent to the upstairs processing facilities as well as electrical and hydraulic power sources. The space allocated for the Hardware Testbed and staging areas was sized to accommodate a prototype flight segment of 15 ft. diameter and 15 ft. height.

#### **7.2.3.3 Guidance & Navigation**

Several requirements drove the location and configuration of this GBT resource lab. The future configuration of this lab called for dual 3-axis tables. The 10 x 25 x 10 foot isolation pad accommodates these units and the associated optical alignment equipment. The size of the pad and the ability to have a line-of-sight access to the North Star for alignment dictates the location within an addition on the north side of Bldg. 4476.

#### **7.2.3.4 Placement of Other GBT Resources**

Due to the fluid nature of the already planned facility modifications and the August 1990 Phase I IOC, specific placement of the other GBT resources is felt to be premature. Temporary facilities will have to be provided while Bldg. 4476 is being modified.

### **8.0 GROUND BASED LAB PHASE 1 COST ESTIMATES**

Table 8.0.-1 gives the ROM costs associated with the Phase 1 GBT. Note that these costs do not reflect any fees or expenses associated with procurement. The hardware and software prices are "list prices". Software development costs reflect only a flat hourly cost.

HLVC/MAST Costs	Description	COST	Display Center	
<b>Hardware</b>			<b>HARDWARE</b>	
Main Processor System	Concurrent (Goldrush/Scirocco)	\$252,100	Graphics Processors (4 each)	(same as S/W Dev Lab)
Main Control Processor System	Masscomp (MC6755-4 CPUs)	\$186,000	Large Screen Monitors (2 each)	\$10,000
Graphics Monitor/processor		\$15,000	Hard Copy Processors	\$6,000
Mass Memory		\$111,250	Projectors	\$550
Hard Copy Processors	2-Lasers, 1 HS line printer	\$12,000	Video Recorders (2 each)	\$3,000
			Network/Bus interface	
			Projection screens	\$600
			Demo Center Furniture	\$2,000
<b>Software</b>				
Main Processor Operating System		\$3,000		
Multi Tasking Graphics Executive	Dataview	\$20,000		
Fortran System		\$3,000	<b>Software</b>	
C3 Ada System		\$30,000	Graphics Programs	1000 hrs \$48,000
			Graphics Tools	\$27,000
Program Executive & Menus	1000 hrs	\$47,980	Element Total	\$97,150
Simulation Program & Menus	2200 hrs	\$105,556	<b>Software Development Lab</b>	
Simulation Model Data & Menus	2200 hrs	\$105,556	<b>Hardware</b>	
Mission/Vehicle/Environment Models	2400 hrs	\$115,150	Workstations (4 Units)	Compacts 186
Software Development Aids & Menus	240 hrs	\$11,515	Archive Storage	\$80,000
Inter-Lab Connections & Menus	160 hrs	\$7,677	Graphic Printer	
			Network/Bus interface	\$20,000
Element Total		\$1,025,784		
<b>Avionics Hardware Test Bed</b>			<b>Software</b>	
<b>Hardware</b>			<b>Software Development Tools</b>	
Master Input/Output Interfacing Unit		\$116,000	Data Dependency Analysis	\$30,000
Local Terminal/Monitor		\$20,000		
PCM DeCom & Data Processor		\$60,000		
Vehicle Bus Analyzer		\$45,000	Element Total	\$130,000
Network/Bus interfaces		\$4,300	Combined Element Totals	\$227,150
Benchies & I/O Hardware			<b>Guidance &amp; Navigation Lab</b>	
<b>Benchmark Hardware</b>			<b>Hardware</b>	
G&N Sensors	INU #1	\$1,300,000	3 Axis Table	\$560,000
Flight Control Processor	INU #1		Environmental Chamber	
SubSystem Controller	RVU #1	\$500,000	Test Controllers (3 Units)	\$60,000
Data Processing System	MDU #1	\$250,000	Input/Output Interface Unit	\$50,000
Flight Control Sensors	RGU & AA #1		Optical Alignment Equipment	\$10,000
Data Bus Interfacing Unit	DBIU (Orbiter/SRB)		Printers (2 Units)	\$10,000
Remote Data Unit	RDU	\$250,000	Inertial Test Set	\$50,000
<b>Software</b>			Misc Test Equipment	\$10,000
Inertial Sensor Models	INU #1 (160 hrs)	\$7,677	<b>Software</b>	
P/C Processor Models	INU #1 (160 hrs)	\$7,677	Inertial Sensor Evaluation Models	400 hrs \$19,192
S/S Controller Models	RVU #1 (160 hrs)	\$7,677	Table Control	\$15,000
DPS Models	MDU #1 (160 hrs)	\$7,677	Operating System/Drivers	\$50,000
P/C Sensor Models	RGU & AA #1 (160 hrs)	\$7,677	Integrated Testing S/W	\$100,000
Engine Controller Models	EIU #1 (200 hrs)	\$9,596		
Cross-Channel Communications	120 hrs	\$5,758	Element Total	\$934,192
Synchronization & Skewing	80 hrs	\$3,838		
Instrumentation	160 hrs	\$7,677	<b>TOTAL GBT PHASE 1 Development Costs</b>	<b>\$4,855,256</b>
LRU Evaluation	1200 hrs	\$57,576		
PCM DeCom & Data Reduction				
Element Total		\$2,668,130		

TABLE 8.0-1 PHASE 1 GBT COSTS

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## 9.0 SUMMARY AND CONCLUSIONS

The purpose in defining the philosophy, objectives and desired functional capabilities of the Ground Based Testbed was, of course, to provide a basis for implementation planning. Successful implementation will be judged upon the GBTs ability to provide timely and cost effective support to Shuttle C, STV and other emerging programs. Figure 9.0-1 reviews the basic functions provided by the GBT. The other factor which can not be neglected is funding for the implementation and operation of the GBT. All of these factors will be summarized in this section.

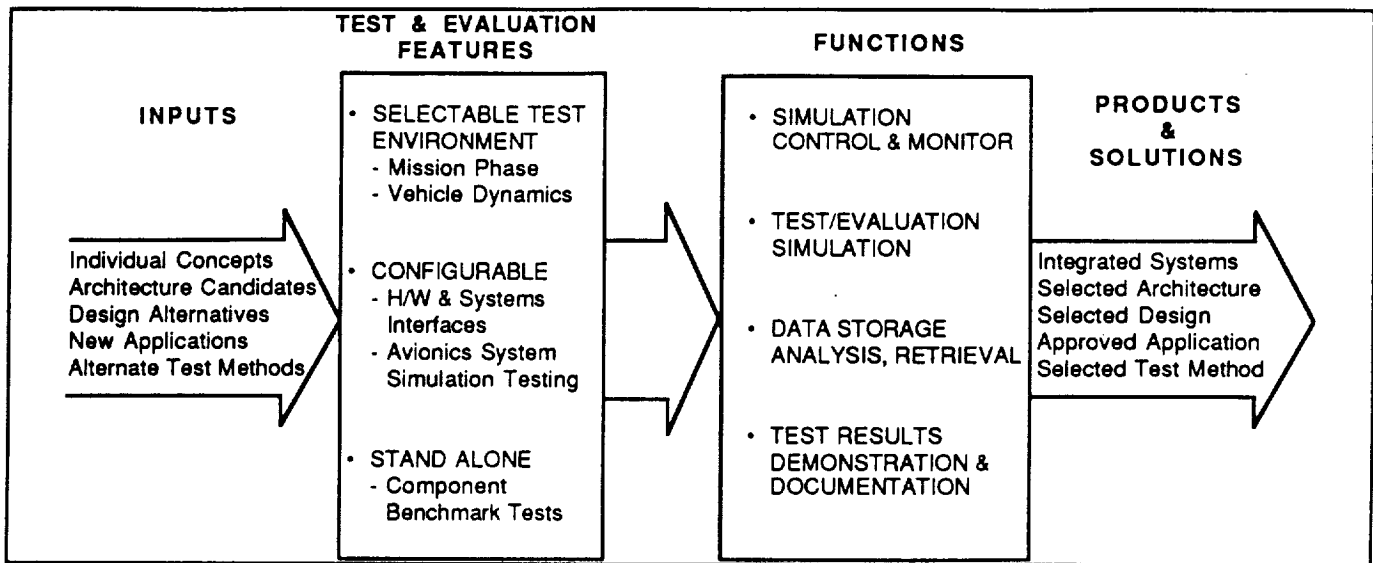


FIGURE 9.0-1 GBT FUNCTIONS

## 9.1 GBT Functional Design

To perform the Functions and provide the Test and Evaluation Features shown, the GBT design evolved into several functional elements. These elements in turn were sized to support specific program driven capabilities and requirements. The development of element capabilities was paced by projected funding levels and prioritized program support requirements. Where possible, provisions were made to use existing, related test and evaluation resources. These provisions, in most cases, not only provide an earlier operational capability, but also extend the original resources capabilities and effectively extend its operational life.

The primary functional elements of the GBT are shown in Figure 9.1-1 and will be discussed in the following paragraphs.

### 9.1.1 GBT Core

The GBT has been described as spanning the test continuum from pure simulation to hardware performance evaluation. Common to each extreme is a flexible, high through-put core processor. The GBT core has a main processor which is functionally divided into the primary processor and the avionics system simulator. The primary processor function includes running the simulation of the test vehicle dynamics, the mission environment and all other interfacing elements to the vehicle avionics system. The avionics system simulation function includes running the simulation of the test vehicle avionics system. This includes the monitor and control of all interfaces to real hardware being tested or run on the Avionics Hardware Test Bench.

Selection of this processor was one of the most important and far reaching design decisions of the study. The unit chosen combined an excellent cost to performance ratio with a software and hardware migration path capable of supporting the rapidly expanding simulation demands of the immediate future. Initially sized with a through put in excess of 150 Million Instructions per Second, (MIPS), this expandable core processor has the



software tools and I/O ports to support the GBTs current and future Real-Time simulation requirements.

The four other main elements of the GBT core are the Main Control Processor, Mass Storage Unit, Hard Copy Processor and Interconnecting network/buss structure. The Main Control Processor is primarily tasked with the allocation and control of GBT resources. It controls most of the various busses and networks running throughout the GBT and supervises use of the Mass Storage and Hard copy Processor. While functionally a part of the GBT Core, the Main Control Processor will probably reside in the Main Control and Demonstration center.

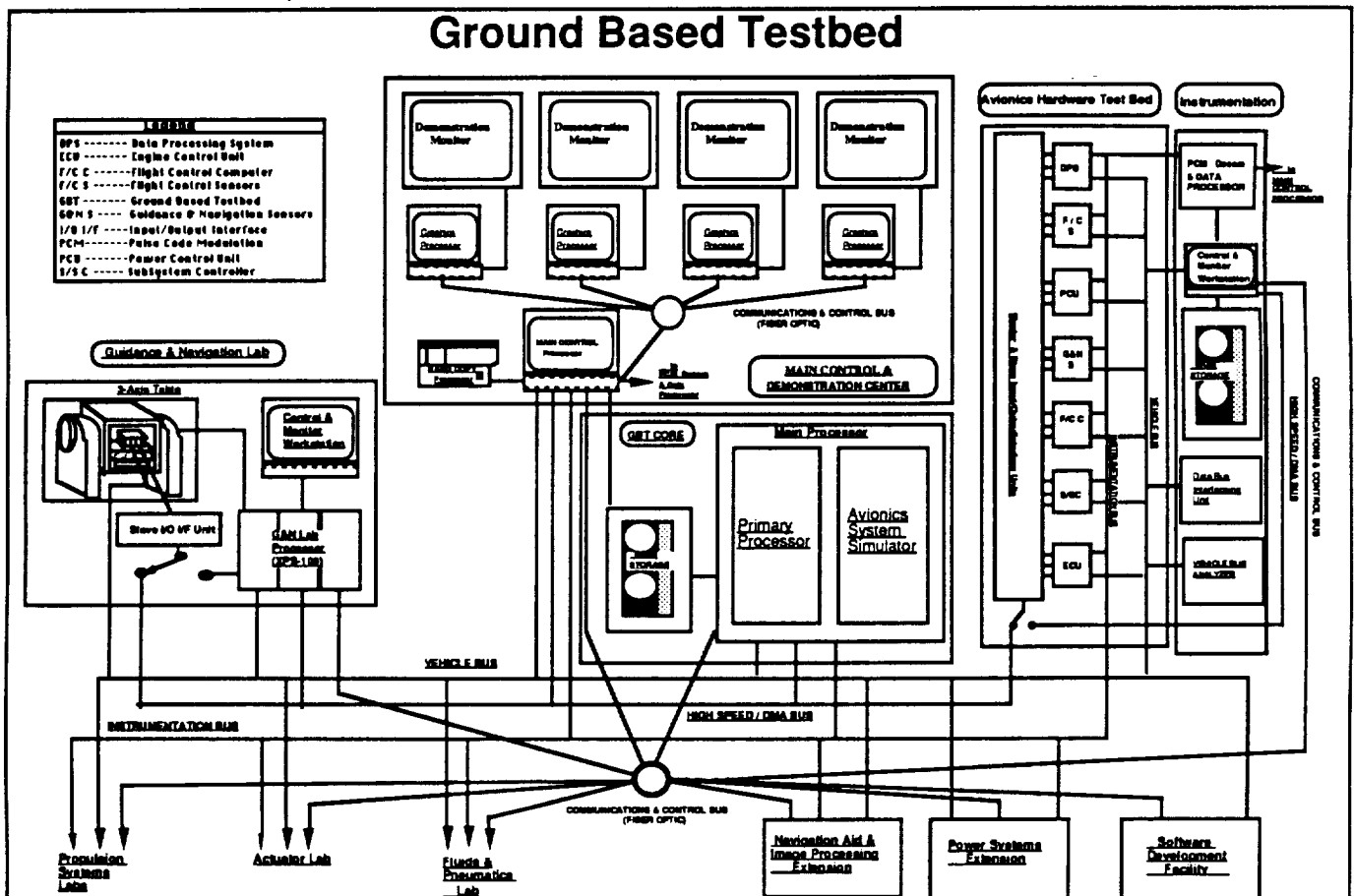


FIGURE 9.1-1 GROUND BASED TESTBED TARGET CONFIGURATION

### 9.1.2 Main Control & Demonstration Center

Within this element rests the primary control and allocation of all the GBT resources. Central to its function is the Main Control Processor that is linked to all the available resources by an extensive inter / intra lab communications network. The Main Control Center and Demonstration Center are collocated because of their complementary functions. The Demonstration monitors may be used to supplement the status displays available to the core's Main Control Processor. The graphics processors will also supplement the Main Control Processor in controlling parallel operations going on within the GBT.

The Demonstration Center primarily consists of four graphics processors driving four large screen monitors. The graphics processors are used to develop display and other support

type graphics. Working with the large screen monitors, the processors can reproduce demonstration graphics depicting anything from real-time test parameters to reproduction of demonstration graphics.

### **9.1.3 Avionics Hardware Test Bed**

The Avionics Hardware Test Bed is the third major segment of the GBT Target Configuration. It contains the interfacing units, busses and harnesses necessary to accommodate the GBT Benchmark hardware. The benchmark hardware is a collection of current avionics units which, when connected to the required interfacing harness, comprise a fully functional avionics system. It provides a real world performance standard to which the candidate hardware can be compared. The Avionics Hardware Test Bed therefor facilitates development and evaluation of new avionics systems, and components by providing a high fidelity, native environment in which they can be tested.

### **9.1.4 Guidance & Navigation Resource Lab**

The G&N Lab is one of the most important resources available to the GBT. Though capable of fully independent operation, in an acceptance test procedure role, its primary value is in closed-loop simulation of an integrated avionics system. The precision 3-axis table can supply all necessary stimuli, except acceleration, to evaluate the best inertial elements of the HLCV era. The Slave I/O interface box will provide the local real-time interfaces to accommodate such testing.

### **9.1.5 Instrumentation Resource Lab**

The Instrumentation segment is a subset of the Avionics hardware test bed that permits local control and monitoring of the test bed hardware or units under test. It functionally duplicates an instrumentation ground station and is equipped to analyze vehicle bus traffic.

### **9.1.6 Software Development Facility**

A major design driver is the architecture of the user friendly software that yielded the efficient and highly compatible interface for potential users. The cost effectiveness of GBT usage rests squarely on its accessibility and its ability to accommodate several tasks in parallel. This translates to a modular set of software tools, tailorable to specific applications and executed with data that bounds the required performance regimes. The tailoring and selection of appropriate performance data is accomplished by a menu driven linkage process. The Software Development Facility will initially be located in the Main Control and Demonstration Facility while the basic GBT operational and benchmark software is being integrated. As the GBT phases into operation, the function of this element will shift to the primary user interface. It will become the site where users will assemble the modularized software tools and simulations into the desired testing regimes. The Software Development Facility will also host the building of the demonstration graphics.

### **9.1.7 Navigation Aid & Image Processing Extension**

This GBT extension is scheduled for Phase 2 implementation. It is designed to provide developmental support for the autonomous rendezvous and docking aids in the near term and approach and landing systems for the far term Fly Back Booster. See HLCV Second Quarterly Review, Thursday 22 September 1988 for details.

### **9.1.8 Power System Extension**

This GBT extension will be capable of testing new technologies in Power Systems components and architectures. This Phase 2 extension will support not only the normal evaluation of candidate power system sources and architectures, but will be focused on EMA power supply development and testing.

### **9.1.9 Fluids & Pneumatics Lab**

This GBT extension facility contains the hardware and special test equipment needed to test the new Fluids and Pneumatic architectures and components. The Fluids & Pneumatics Lab contains flow and pressure sensing equipment, pressure regulation equipment, electronic valves, a facility processor, a VME bus input/output interface chassis, and bottled fluids and gases. The extension facility shall have thick safety walls and a pressure pit for this high pressure LN<sub>2</sub>. The facility shall also be capable of running remote when operating with the high pressure.

### **9.1.10 Actuator Lab**

This resource lab will provide a dynamic performance evaluation facility primarily aimed at larger, fast response actuators used in Trust Vector Control systems. With the emergence of large numbers of clustered engines as a solution to the heavy lift booster requirements, EMAs are gaining popularity. The advantages of being able to link the Power Systems and Actuator Labs together via the GBT is seen as an attractive Phase 2 capability.

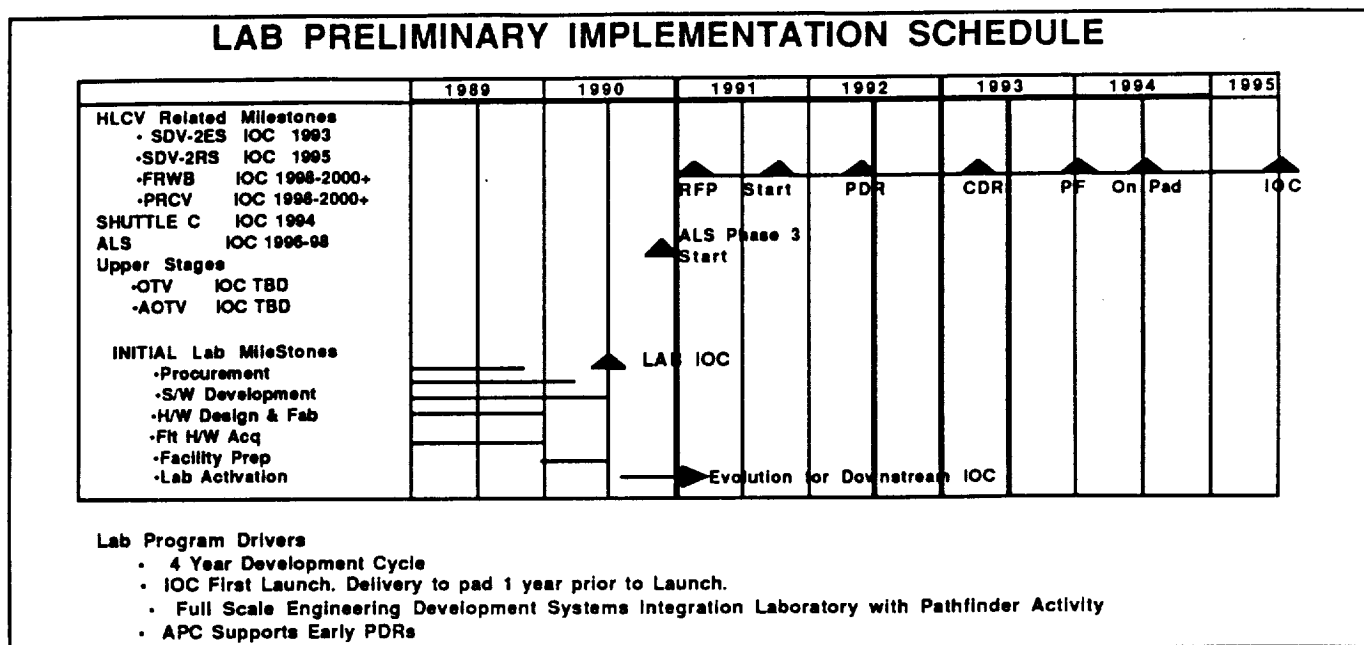
### **9.1.11 Propulsion Systems Labs**

MSFC has long been the site of propulsion system development and test. The GBT would provide a way to combine the existing, high fidelity, propulsion system hardware emulations and simulations with the avionics system simulations to provide integrated, end to end testing. Particularly useful will be the capability to evaluate control system performance using the clustered engine configurations of the future.

## **9.2 GBT Implementation**

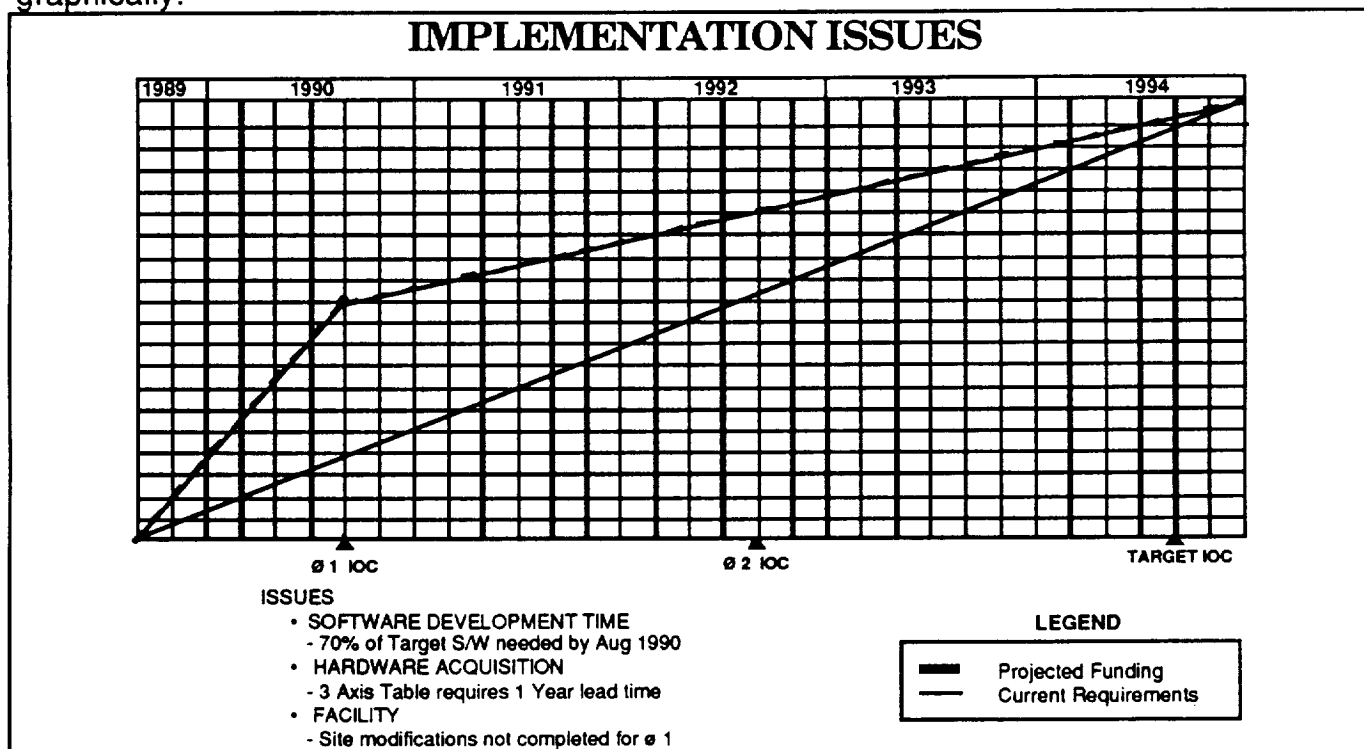
From the beginning, it was recognized that the Ground Based Test beds capabilities would be tied to meeting current program system testing requirements. The GBT's role was to encompass vehicle simulation and testing needs from inception to the Preliminary Design Review (PDR). Looking at the projected vehicle developmental schedules, it was all too clear that the first operational GBT capabilities would have to be focused on the critical developmental problems. If vehicles like the Shuttle C or STV were to be supported prior to their PDR's the GBT must be at least operational by August 1990.

Software model development is another key factor in the implementation plan. Fidelity of the vehicle dynamic and system models is critical to establishing the GBT as a valuable program development resource. This usually requires actual hardware being used to develop and verify the fidelity of the respective software models. Availability of similar hardware often proves to be another pacing element. The basic GBT hardware and software design is modular and thus can be changed easily to accommodate different requirements. The early phases of implementation require the building of a specific number of these basic modules to satisfy a limited number of needs. To satisfy a greater set of requirements relatively few new modules are required.



**FIGURE 9.2-1 IMPLEMENTATION SCHEDULE**

Figure 9.2-1 shows an early implementation schedule and its assumptions. One of the most difficult problems of the implementation schedule, shown earlier in figure 1.2-2, is the amount of work to be done in the first phase. Between February 1989 and August 1990, over 60% of the total task must be accomplished. This is not consistent with the relatively low front end funding guidelines that were provided for this study. Figure 9.2-2 shows this problem graphically.



**FIGURE 9.2-2 PROJECTED FUNDING LEVELS VS TASK**

